PROCEEDINGS

MODERN CONCEPTS IN URBAN DRAINAGE

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FOREWORD

The Government of Canada and the Government of Ontario in 1971 started a cooperative program to ensure that the water quality of the Great Lakes is restored and protected. One aspect of the program was the funding to a total extent of $1.5 million for investigative work to define urban drainage problems and develop techniques and solutions to the problems. In this endeavour, assistance was provided by funding from the Canada/United States Agreement on Great Lakes Water Quality, and Central Mortgage and Finance Corporation.

A conference entitled "Modern Concepts for Urban Drainage" was held on March 28-30, 1977, in Toronto, Ontario, to culminate and report four years of research and development in this field by the Federal and Ontario governments. The area covered by the conference included all aspects of urban drainage from its pollution and hydrological impact through to new methodology and criteria for its control.

The papers presented at the conference provided an overview of the Canada-Ontario Urban Drainage Program, pollution sources, their effects, the applications of computer models for analyzing urban drainage problems and a review of existing practice and policies. The conference was designed to discuss in a practical and economic way many of the questions concerning urban drainage, and was of interest to those involved in either the administrative or technical aspects of urban runoff.

The attendance at the conference was about 400, composed of municipal engineers, elected officials, consultants, planners and the staff of regulatory agencies involved with urban runoff. The attendees were approximately from the following sources:

Federal Government Employees	7%
Provincial Government Employees	18%
Municipal Government Employees	15%
Consulting Engineer Employees	52%
Other	8%

AVANT-PROPOS

En 1971, les gouvernements du Canada et de l'Ontario mettaient sur pied un programme coopératif pour restaurer et protéger la qualité de l'eau des Grands lacs. Le programme consacrait, entre autres, une somme totale de 1,5 million de dollars à l'étude des problèmes des eaux pluviales en milieu urbain et à la mise au point de techniques et de solutions appropriées. Ces entreprises ont bénéficié d'une aide financière en vertu de l'Accord Canada-États-Unis relatif à la qualité de l'eau dans les Grands lacs et d'une contribution de la Central Mortgage and Finance Corporation.

On a tenu à Toronto, du 28 au 30 mars 1977, une conférence intitulée Modern Concepts for Urban Drainage pour communiquer les résultats de quatre années de recherche et de dévelopment dans ce domaine par les gouvernements canadien et ontarien. La conférence touchait à tous les aspects des égouts pluviaux, depuis la pollution et les incidences hydrologiques aux nouvelles techniques et aux critères d'assainissement.

Les communications présentées au cours de la conférence donnaient une vue d'ensemble du Programme Canada-Ontario d'égouts pluviaux urbains, des sources de pollution, de leurs effets et de l'utilisation de modèles informatiques pour analyser les problèmes dans ce secteur. Elles examinaient aussi les pratiques et politiques actuelles. La conférence avait pour but de susciter le dialogue sur les aspects pratiques et économiques des égouts pluviaux en milieu urbain et s'adressait à ceux qui traitent les aspects administratifs et techniques de la question.

Environ 400 personnes intéressées au domaine des eaux pluviales (ingénieurs municipaux, représentants élus, experts-conseils, planificateurs et responsables des organismes de réglementation) y ont participé; voicie comment elles se distribuaient:

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INTRODUCTION

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The seminar on Modern Concepts of Urban Drainage represents the culmination of approximately four years of investigations and studies on many aspects of urban drainage carried out through the Urban Drainage Subcommittee (UDS) under the Canada-Ontario Agreement on Great Lakes Water Quality.

This introductory paper will outline briefly the background on the intergovernmental agreements which led to the formation and funding of the UDS. It will review the general concerns with urban drainage which the subcommittee intended to address and outline the specific terms of reference under which it would function.

The various activities, programs and studies of the UDS will be highlighted, with specific reference to those which will be discussed during the course of the seminar. Finally, a discussion will be presented to outline the aims, objectives and direction which policies for urban drainage control will likely follow.

BACKGROUND

The Government of Canada and the Province of Ontario, in August 1971, entered into an agreement - the Canada-Ontario Agreement on Great Lakes Water Quality - to accelerate the abatement of pollution in the Lower Great Lakes. The agreement was consummated in response to recommendations of the International Joint Commission (IJC) on remedial measures and in anticipation of the Canada-United States Agreement on Great Lakes Water Quality, which was signed in April 1972.

One of the provisions of the Canada-Ontario Agreement was the funding of a research program directed towards reducing the cost of municipal pollution control, by ensuring that the latest in technological advances were incorporated into such programs. Funding was to be on a shared basis, with each government contributing equally to a total of $6 million over the five-year term of the agreement.

To oversee this and other provisions of the agreement, the two governments set up a Board of Review and a Technical Committee. The Committee's prime responsibility was to propose and review research proposals and to make appropriate recommendations to the Board. Four subcommittees were set up under the Technical Committee, one of which was the Urban Drainage Subcommittee (UDS). Funds for the UDS research programs were provided through both the Canada-Ontario and Canada-United States agreements.

AREAS OF CONCERN

The Urban Drainage Subcommittee was formed in specific response to IJC recommendations on the need for control of pollution caused by combined sewer overflows. The general significance of these pollution sources had been investigated and reported on for some time. Information obtained through studies in several American and a few Canadian cities showed that the composition of combined sewage overflows can be comparable to that of raw or primary treated sanitary sewage. There seemed little doubt that the pollution potential was significant and controls would be necessary. What was not readily available was a means of analysing very complex sewer networks to determine the quantity, quality and frequency of overflow and determining the most cost-effective methods of control. Developing this capability was to be one of the subcommittee's major undertakings.

There was mounting evidence also that storm water itself was a potential source of pollution and the question of the need for its treatment was receiving considerable attention. The Board of Review agreed with recommendations that this area should be addressed. Studies would be necessary to substantiate the pollution potential and to explore means of controlling it.

The rapid rate of runoff from developed areas was another of the more significant storm water-related problems. Urbanizing an area will usually increase the rate of runoff several fold over that which occurred under natural conditions. The present practice is usually to get rainfall off rooftops, parking lots and roadways just as quickly as possible and discharge it to the nearest receiver. The effect on many

streams and streamflow has been dramatic; hitherto minor depressions have been subjected to extreme peaks of flow and have been transformed into deep, eroded and scoured gullies, swollen and turbid during rainfall, dry shortly afterwards. A significant portion of groundwater recharge has been eliminated due to the impervious surfaces, and base flow to streams is lost. Costly channel improvements are necessary in many cases to overcome local flooding problems and to replace undersized downstream structures.

Another runoff-related problem is the sediment transport to streams as a result of soil erosion at construction sites - commerical, residential and industrial sites, transportation routes, etc. The vegetation cover is often removed from extensive tracts of land, in some cases months or years in advance of the actual construction phases, storm drainage works are installed and the area is graded to provide suitable drainage, thereby accelerating the amount and rate of runoff and the accompanying sediment load. Practice of this type obviously leads to water quality deterioration, and the need for improved practices and control in this area is essential.

TERMS OF REFERENCE

Recognizing the foregoing problems in a general sense, the Urban Drainage Subcommittee undertook to develop a program which would define the problems, develop a means of solving them and develop a strategy for implementing the solutions. The specific terms of reference were to:

1. establish studies to define the magnitude of the pollution problems due to urban runoff;
2. establish studies directed toward potential solutions to urban runoff problems; and
3. develop a strategy for implementing solutions.

Attempts had been made in other jurisdictions to define the problems and develop solution capability, but there was some uncertainty as to the direct applicability to Ontario conditions. It was considered necessary, therefore, to develop studies which would provide information on storm water quality, assess the suitability of a combined sewer overflow and storm water control methods, develop and test under local conditions

predictive capabilities of mathematical storm water management models and develop a storm water management program which would reflect the Ontario situation.

URBAN DRAINAGE STUDIES

A number of studies were done internally by the Federal Department of Fisheries and Environment and the Ontario Ministry of the Environment. Scientific liaison was provided by the two agencies for studies done through external contracts with universities, consulting firms and municipalities.

For the most part, the papers to be presented during the course of the seminar will deal with specific study areas related to the activities and programs of the subcommittee. However, in order to provide as comprehensive an overview as possible on all aspects of urban drainage, discussion will be provided on the results of studies done in other jurisdictions where they complement the UDS programs. In addition, papers were invited to present the municipal viewpoint and perspective as regards existing drainage practices, the problems they present and the implications a future control program might have. Finally, the experiences directly related to the application of new urban drainage design techniques will be outlined.

A brief review of the various subject areas to be discussed will be presented, following, where practical, the three defined categories - problem definition, solution capability and implementing solutions.

PROBLEM DEFINITION

Storm water quality studies were done in the boroughs of East York and North York and in the City of Burlington on totally separated sewer systems. The latter two studies were initially set up to obtain rainfall-runoff correlations for use in simulation models, but, having instrumented the test sites for quantity determinations, it was a relatively simple task to adapt to quality monitoring. All three sites were basically residential, but the Burlington site included a shopping plaza. Snowmelt quality and quantity determinations were also made at the North York site. Detailed results of these studies will be provided as part of various papers during the course of the seminar. Suffice it to say at this time

that for a number of parameters traditionally used to gauge wastewater quality - BOD, suspended solids and coliform concentrations - runoff in Ontario urban areas can be quite contaminated at times. There is also a strong correlation between quality of runoff and the interval between rainfall events, suggesting that the build-up of contaminants could be controlled by improved street sweeping practices or increased frequency.

A study undertaken at the City of Guelph was intended to determine the effect of runoff from an urban area on a major receiver, in this case the Speed River. Data collected from two urban catchment areas in the city and from the river upstream and downstream from the city were applied to simulation models (SWMM and STORM). Details of this application will be provided.

The American Public Works Association (APWA) had done studies in several American cities to determine the magnitude of storm water related pollutant discharges and the cost of remedial measures. Having developed the technique, capability and program, it was deemed advisable to contract with APWA to define the gross pollution load from Ontario cities. Data were provided on several major urban centres and, although some additional interpretation of the results is still required, figures on the gross pollution loads and cost of control measures have been developed.

Three municipal sewage treatment plants were studied to determine the extent of raw sewage bypass during rainfall events. It is of interest to note that one of the plants was bypassed 24 times in a nine-month period, averaging over six hours per event. Controls in this area will be essential.

SOLUTION CAPABILITY

As stated earlier, one of the primary objectives of the Urban Drainage Subcommittee was to make available for general use a storm water management model(s) which would provide a means of reviewing existing sewer networks to determine the extent of combined-sewer overflows. Such models are the Stormwater Management Model (SWMM), developed by the U.S. Environmental Protection Agency, and the Storage, Treatment, Overflow and

Runoff Model (STORM), developed by the U.S. Army Corps of Engineers. While they had been applied with some success in the U.S., some modifications and updating were required in order to adapt them to Canadian conditions. To modify and verify the predictive capabilities of these models has been one of the subcommittee's major programs. The development of this program will be outlined. Two separate workshops have already been held to explain the details of this program and to provide potential users with an opportunity to become familiar with the models.

Two test sites, one in the City of Hamilton, the other in the Borough of East York, are currently being monitored to assess what happens in selected combined sewer areas. The models will be employed to simulate conditions in these two catchments and the accuracy of the predictions verified with the actual on-site measurements. Initial indications are that the quantity simulation is excellent, while quality - a much more variable parameter - may not be as predictable. Initial findings will be discussed.

Wherever possible, real data, which had been obtained in problem definition studies here and elsewhere, were used to develop the storm water management models, to verify the predictions and to enable refinement. Such applications were snowmelt data from the City of Halifax and the Borough of North York.

Comparisons were made of the predictive capabilities of a number of urban runoff computer models and the Rational method using existing data from a number of test areas in Canada and the U.S. The accuracy and consistency of the models were assessed for peak flows, times to peak, runoff volumes and the complete hydrograph. These will be covered in some detail as part of the "Review of Urban Runoff Models".

Several treatment systems and control devices were tested, some through field applications, others on a bench scale. These included fine-mesh screens, ozone, flocculation, flotation, the "Swirl" concentrator (funded by Metro Toronto and CMHC) and a proprietary reduced-orifice device, the Hydro-brake. All of these will be referred to later.

The influence of existing sewers and appurtenance design on bypassing was also investigated with the view to reducing energy losses through design modifications.

A study was done on a proposed subdivision in the Town of Milton to compare the economic and environmental features of combined and separate sewer systems and to investigate alternative storage methods. It was found that a combined sewer system was only slightly less expensive than a separate system and small savings in sewer costs resulted when storage was incorporated. Roof ponding could reduce peak sewer flows by 30 percent and catch basin storage a similar amount. Detention ponds proved to be the most effective means of modifying storm water flows.

IMPLEMENTING SOLUTIONS

One of the first applications of SWMM and STORM was to develop control methods to reduce the impact that a storm water discharge from a residential, commercial industrial complex in Nepean Township would have on the Rideau River and, subsequently, three downstream bathing areas. The study was funded jointly by the Regional Municipality of Ottawa-Carleton and the UDS. The feasibility of storage and detention of storm water on rooftops, parking lots, streets and in a large-diameter storm sewer as measures for attenuating the predicted five-year peak discharge of 750 cfs was investigated. The need for disinfection was to be assessed after the first phase of development.

A review was made of practices in a number of countries - Great Britain, France, Germany, Sweden, Switzerland and the U.S. - to determine their experiences with storm water discharges and combined sewer overflows. Of considerable interest was determining statutory policies governing their control. The conclusions which can be drawn as a result of these reviews is that while these countries recognize the extent of the problem, they have no readily applicable solution in place and the state-of-the-art and regulatory controls are no further advanced.

Another application of computer models involved the simulation of before and after conditions related to runoff from a proposed residential development and the effectiveness of an on-stream retention pond in reducing contaminant levels and attenuating peak flows. No actual field measurements were used in the exercise. It was expected that the retention device could ensure no deterioration in stream water quality and could control runoff from one-year return period storms to that of pre-development conditions.

A storm water detention facility, which will be referred to later, was constructed to serve the Upper Canada Shopping Mall in Newmarket. The existing downstream storm sewers could not accept the anticipated peak runoff from the area. The solution to the drainage problem required either a separate storm sewer 4,000 feet in length to an "acceptable" receiver or some means of reducing the peak flow. An on-site detention pond was selected and it is understood that a substantial cost saving was realized. It is hoped that this facility may be studied to determine the efficiency of the facility as a treatment device.

The City of Winnipeg was faced with very large expenditures to drain developing areas by the conventional methods of storm drainage. Deep, large-diameter sewers were necessary to reach adequate receivers. The city has adopted the concept of draining subcatchments into detention devices, releasing the flows at a controlled rate and thereby making use of local, smaller-capacity receivers. The ponds are aesthetically very attractive and are suitable for limited recreational activities. The UDS assisted the city in developing a study program to show the effect of storage on water quality, reduction in sewer costs and usefulness of the ponds for primary contact recreational activities. The studies were funded by CMHC under its SCAT program.

Through funding provided by CMHC, a systems demonstration project has been undertaken in the City of St. Thomas. The city has a history of local flooding, combined sewer overflows and sewage treatment plant bypasses. SWMM and STORM will be used to predict the frequency, quality and quantity of bypasses and overflows, design system changes to control flooding problems and to determine the effects of discharges on the receiving stream. A cost-effective control program will be developed as a result. This project will be discussed in some detail.

Another major undertaking of the subcommitte was the preparation of a "Manual of Practice in Urban Drainage", which is to be discussed towards the end of this conference. The manual has been prepared by a committee representing the Urban Drainage Subcommittee, municipal governments and a number of Ontario ministries whose interests or responsibilities relate to urban drainage problems and their solutions. It attempts to examine the whole system within which urban drainage problems arise

and are solved, and to outline administrative procedures for implementing solutions.

A paper will be presented which will review most of the models available, giving the capabilities and features of each. It is important to emphasize that while we have directed considerable effort towards the development of SWMM and STORM, we do not consider them the only ones acceptable. They are non-proprietary, and some users may consider this an advantage. Some, however, will choose to use the proprietary models and the engineering services that go with them. This is entirely acceptable.

POLICY CONSIDERATIONS

The Urban Drainage Subcommittee is not, in itself, in a position to set policy on storm water management. The problems have been well defined, or confirmed, in the context of the Ontario situation; solutions to these problems are also well defined and there is sufficient indication that program implementation is now an attainable objective. The next activity of the subcommittee will be to develop a program of policy implementation. The policy recommendations will be forwarded to the senior levels of government for consideration. Four general categories will be identified.

1. Rate of Runoff Control

Policy in this area will relate to new developments, primarily in headwater reaches of streams, and as an objective will embody the principle that post-development runoff should not exceed that which would have occurred from the area under natural conditions. The majority of scouring, streambed erosion and bank undercutting takes place because of the regular runoff occurrences, and it is likely that controls will relate to the one-to-two-year storms. It must be emphasized that this is an objective which cannot necessarily be applied everywhere. It may be necessary to continue to have downstream areas drained as quickly as possible to provide channel capacity when the retained flows from the upper reaches arrive. In-channel controls, bank and streambed stabilization in the lower reaches will likely be necessary to prevent streambank and streambed erosion. Comprehensive watershed planning will be essential to optimize the drainage capabilities of the watershed in keeping with

maximum channel protection and flood control. The ideal way to ensure that problems are avoided is to consider storm water management at the earliest possible stage in any development.

A change in the general philosophy on the part of municipalities will be required in many cases. Roof water may have to be excluded from minor drainage systems, bylaws may be required to compel rooftop and parking-lot storage in industrial and commercial areas, land normally deeded for parks may be required for detention facilities, street cleaning may have to increase in frequency and efficiency, and some additional maintenance expenses may have to be accepted. The benefits will manifest themselves in avoiding the subsequent need for channel improvements and in reduced flood-damage costs and, of course, improved water quality.

There has been some consideration of the retroactive control of the rate of storm water runoff from developed areas. Needless to say, in some areas this problem will have to be addressed. Indeed, many municipalities are now faced with investigating and implementing remedial measures for flood-damage reduction. Unfortunately, they are finding that the options available to control it have been drastically reduced because the original design did not envisage the need. Although inlet controls and diversion of certain flows will allow some relief, channel improvements (straightening and stabilizing) will probably be the most common improvements. Channel capacity will be increased and as a side benefit, erosion-related water quality problems will be reduced.

2. Erosion and Sediment Transport Control

The objective in this area relates to the reduction, to the extent practicable, of material eroded and transported from construction sites. Control will best be employed in this area by restricting the amount of vegetation which may be removed and by trapping the materials that are inevitably going to erode. Sediment traps, strategically located throughout the site, or sedimentation basins at the major points of discharge, i.e., storm sewer outlets, will be employed.

There are a few jurisdictions which now have top-soil removal and erosion-control legislation and regulations in effect and these will be very valuable in the formulation of a policy in this area. Erosion-control measures should be considered in the very earliest planning stages of any development.

3. Existing Systems Review

The drainage systems in the older areas of most of our cities are rather complex. A city may have several points at which bypass takes place. The frequency, quantity and quality will vary from point to point and, indeed, at a specific point due to variation in intensity and duration of rainfall, interval between rainfalls, the accumulation of street surface contaminants and in-sewer sludge deposits, and, because the strength of dry-weather sewage varies quite significantly, the time of day the rainfall event occurs. Accordingly, the impact on the receiver will vary from event to event. To define the impact on other than a gross basis would be an impossible task.

What will be recommended for this aspect of the storm water management program will be a detailed systems review in each municipality, undertaken by the municipality, to determine the points of bypass and the frequency, quantity and quality of bypass at each point under a variety of rainfall events. Having defined the extent of the problem, a cost/benefit analysis should be done on control measures, a program adopted and a schedule of implementation stipulated. The program and scheduling will have to be reviewed with and agreed to by the regulatory agencies.

The time for this detailed review will likely be about two years from the date of policy announcement. This should be sufficient time to enable the gathering of the physical details of the drainage system (catchment area and sewer system), doing preliminary modelling runs, collecting quantity and quality data to refine the predictions and complete the control program selection.

As a first step, it would be advisable to review the contributory drainage area when an extension to existing sewage-treatment works is contemplated. With the eventual requirement for overflow control, it will be necessary to examine the economics of providing the controls at various points within the system or at the plant site.

The tools are available to do this detailed systems review and the methods for reducing combined-sewer overflows are available, so the development of a program to fit the needs of a given municipality is a readily attainable objective.

4. Storm Water Treatment

In some areas of the province, the nature of the use of some rivers and lakes dictates the need for special consideration of discharge quality. The degree of treatment required will be beyond that which will be provided by facilities installed for rate of runoff control. Sedimentation employed in this latter control will adequately remove most of the "normal" contaminants. But in some cases, effluent disinfection or chemical addition for the removal of finely divided suspended material or phosphorus will be necessary.

A blanket policy statement on this aspect is not realistic. The critical areas will have to be identified and control programs tailored to meet the specific situations. In the majority of cases, the municipalities recognize these areas and the advantages inherent in preserving them, and usually initiate programs which will ensure their protection. Provincial-interest situations will, of course, be looked at by the regulatory agencies and will be identified as requiring special consideration, hopefully early in the development of the area.

URBAN DRAINAGE PROBLEMS - AN OVERVIEW

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INTRODUCTION

Since 1950 the urban population of Canada has increased from just over one-half to over three-quarters of the total population, and over 80 percent of the population of Ontario now lives in urban areas. If present trends continue, the urbanization process, together with increasing population, will by the end of this century, increase the urban population of Canada by an additional 10 million people. About one-third of the increase should be in the population of Ontario, and most of that increase will occur in the Great Lakes Basin.

The urban growth that accompanies this population increase will bring substantial drainage problems in areas of new development, and will aggravate already-existing problems in areas that are presently developed. These problems are, or will be, serious, and solutions will cost billions of dollars. The purpose of this paper is to describe these problems and to show that these expenditures will be justified.

URBAN DRAINAGE PROBLEMS

Urban drainage problems fall naturally into the two broad categories shown in Table 1: problems in already-developed areas, and problems peculiar to areas undergoing development. Figure 1, which shows sources and movements of water and pollutants in urban systems, may help to illustrate some of these problems. Of the pollution sources shown on this figure, only those that are generally described as non-point -- surface runoff, combined sewer overflows and sewerage system bypass -- are considered here. Considerable progress has been made in control of point sources -- discharges from sewage treatment plants and industrial sources -- and the problems and abatement technology are sufficiently well known that further discussion here would be redundant.

TABLE 1. URBAN DRAINAGE PROBLEMS

Problems	Causes	Effects
	Developed Areas	
Combined Sewer Overflows	- conventional interceptors and treatment plants handle only 2 to 4 times dry weather flow	- pollution of receiving water by wet weather overflows of mixed sewage and surface runoff
Urban Surface Runoff Pollution	- build up of pollutants on impervious areas from all urban activities	- pollution of receiving water by nutrients, bacteria, sediment, metals
Overloaded Sewerage Systems	- infiltration/inflow - redevelopment to higher density land uses - development of upstream lands	- local flooding - foundation damage - health hazards associated with sewage backup - pollution of receiving waters by wet and dry weather bypassing of sanitary sewage
	Developing Areas	
Increased Volume and Rate of Surface Runoff; Lowered Ground Water Tables	- removal of protective surface vegetation and paving during construction - drainage systems installed to deal with local flooding - construction in flood plains, and filling of ponds and swamps	- local flooding - erosion, and siltation of receiving waters - reduced base flow in streams - loss of natural storage areas and of recreational and aesthetic amenities
Construction Activities	- top soil removal - heavy machinery disturbs stream banks	- turbidity and sediment in receiving waters

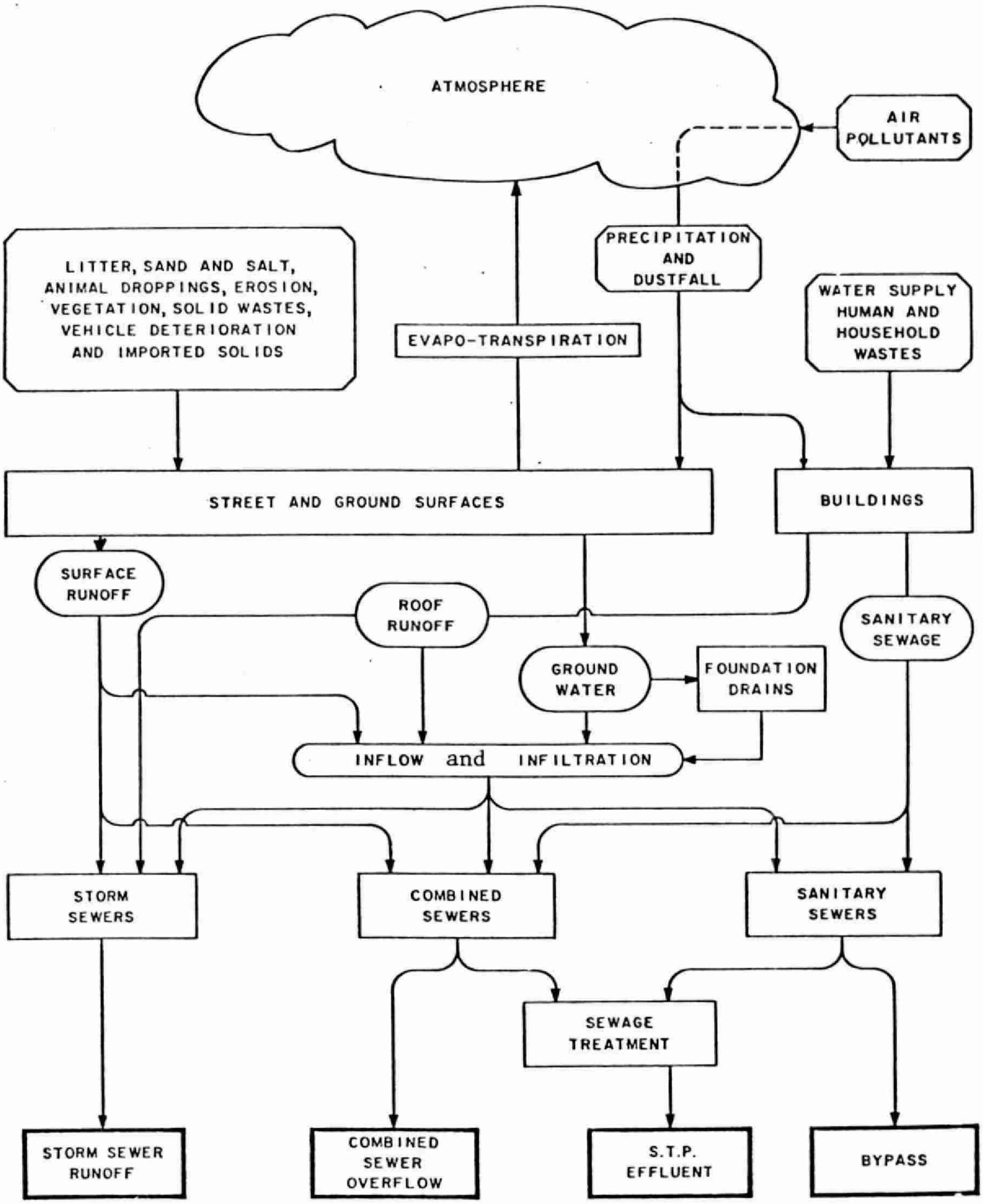


FIGURE I : SOURCES AND MOVEMENTS OF WATER AND POTENTIAL POLLUTANTS IN URBAN DRAINAGE SYSTEMS.

Problems in Developed Areas

The sewerage systems of the older Canadian cities originated as combined systems -- conveying both sewage and surface runoff. Development of these systems was one of the earliest effects of urbanization. In built-up areas, local pollution resulted from the introduction of water-carried sewerage systems and the inability of soil disposal systems to properly dispose of increasing quantities of sewage and stream channels, which had been enclosed to serve as storm sewers, formed the basis of combined sewerage systems when sewer connections from houses and businesses were permitted or required. As these communities developed, combined systems were extended. When interceptors and treatment plants were installed, provision was made for overflows, in wet weather, of flows of mixed sewage and storm water that could, in major storms, be one hundred or more times dry weather flows. Currently about one-half of the urban population of Canada, and about 40% of the urban population of Ontario, are served by combined systems.

Separate sewers -- using parallel pipe systems for sanitary sewage and surface runoff -- are common in newer communities and in extensions of the sewerage systems of older municipalities. One reason for use of separate systems is that in some developments economies were realized by installing only sanitary sewers and delaying storm drainage costs by allowing surface water to flow in ditches and natural channels. Another reason is that combined sewer overflows were recognized as wet weather pollution sources.

Combined sewer overflows

The nature of pollution from combined overflows is indicated in Table 2, which compares the composition of combined sewage with treated effluent. This comparison is made in terms of annual loads in Table 3, which shows that wet-weather loads from combined sewage overflows may be many times larger than loads discharged from treatment plants during storms, and equal or exceed total annual discharges from treatment plants. Effects of discharging large quantities of untreated combined sewage during short time periods during storms include aesthetic effects of floating

TABLE 2. TYPICAL COMPOSITION OF SEWAGE AND STORM WATER

	BOD mg/l	SS mg/l	Total N mg/l	Total P mg/l	Coliform per 100 ml	Fecal Coliform per 100 ml
Raw Sewage	200	200	40	10	10^8	10^7
Treated Sewage						
- Primary	135	80	35	1	10^7	10^6
- Secondary	25	15	30	1	10^4	10^3
Combined Sewage	140	400	11	6	10^7	10^6
Surface Runoff	15	300	4	1	2×10^4	5×10^3

Notes: (a) Values in this table are representative of values recorded in Canadian and U.S. communities.

(b) Ontario total Body Contact Recreational Standards.

Total Coliform 10^3 per 100 ml.
Fecal Coliform 10^2 per 100 ml.

TABLE 3. COMPARISON OF ANNUAL LOAD OF BOD AND SUSPENDED SOLIDS DISCHARGED IN WET AND DRY WEATHER FROM COMBINED AND SEPARATE SEWAGE SYSTEMS (lb/acre-year).

	Primary SS	Treatment BOD	Secondary SS	Treatment BOD
Combined System				
Dry Weather Flow Periods				
- Sewage Treatment Plant	577	937	121	144
Wet Weather Flow Periods				
- Sewage Treatment Plant	124	42	31	7
- Combined Overflows	396	82	396	82
TOTAL	1097	1061	548	233
Separate System				
Dry Weather Flow Periods				
- Sewage Treatment Plant	577	937	121	144
Wet Weather Flow Periods				
- Sewage Treatment Plant	64	104	19	16
- Surface Runoff	600	40	600	40
TOTAL	1241	1081	740	200

Note: Values in table based on the following assumptions:

1. Population 25 persons/acre, 0.17 lb/cap-day SS and BOD, 100 gcpd.
2. BOD removal by primary and secondary treatment of 35 and 90% respectively; suspended solids removal of 60 and 90%.
3. Runoff occurs during 6% of hours.
4. Surface runoff contributes SS-600 lb/acre yr., BOD-40 lb/acre-yr.
5. One percent of dry weather solids and BOD are retained in sewer deposits and flushed out following storms.
6. Annual Runoff = 17 in.
7. Interceptor capacity = 2.5 x DWF

solids and sediment, reduced dissolved oxygen and turbidity that can produce fish kills, and bacteriological effects on water supply sources and recreational areas. On an annual basis nutrient loads and sediment accumulation resulting from combined overflows may be significant in comparison with other sources.

Surface runoff

As attention has been focused on combined sewer overflow problems, another potential pollution source has been recognized: storm runoff from separate sewerage systems. The origins of this pollution are suggested in Figure 1. Tables 2 and 3 compare pollution concentrations and loadings from surface runoff with those in sanitary and combined sewerage.

Coliform concentrations, although low in comparison with values in treated sewage and combined overflow, are high enough to exceed recreational water bacteriological standards. Nutrient concentrations are small relative to those in other sources, but annual nutrient loads may be significant when surface runoff reaches an urban lake.

Surface runoff also serves as the vehicle by which most of the salt used for ice control is eventually removed from streets. Chloride concentrations in runoff, which commonly approximate 20 mg/l, may reach values on the order of 5,000 to 15,000 mg/l in snowmelt and spring runoff. High concentrations of heavy metals have also been measured in surface runoff -- for example, lead concentrations 210 times those in sanitary sewage. Although these metals remain largely insoluble, under certain conditions, such as soft water, copper, lead, zinc and cadmium could be dissolved and could be toxic to some aquatic organisms.

Overloaded systems

Many communities today face serious drainage problems resulting from the combined effects of upstream development, re-development, or inflow and infiltration.

Overloading of trunk sewers as a result of upstream development is an obvious direct effect of the urbanization process. A second, indirect, effect is that as urban areas expand, land uses change in areas close to the centre of cities. Areas that were originally occupied by low-density uses are now used for commercial and high-density residential

use. In these areas, land surfaces become virtually 100 percent paved, and storm runoff is complete and immediate -- exceeding the capacity of drainage systems originally designed for low-density development.

Infiltration and inflow are a third reason why existing drainage systems are overloaded. Sewers, pumping stations, interceptor sewers, and treatment plants are frequently robbed of capacity by groundwater and surface water that they were not designed to accommodate. A good deal of this water appears to enter by way of foundation drains connected to sanitary sewers, through poorly constructed building sewers, illicit connection of roof drains to sanitary systems, or leakage into old combined sewers.

One effect of an overloaded system is local flooding, resulting in both inconvenience and property damage. A related problem is damage to basement walls and floors where foundation drains are connected to a storm or combined system and hydrostatic pressures build up because groundwater cannot escape due to surcharging in an overloaded sewer. If foundation drains are connected to sanitary sewers, infiltration problems in the sanitary system are increased.

Pollution effects of overloaded systems include health hazards where combined sewage backs up into streets or basements, and by-passing of untreated sewage when the capacity of interceptors, pumping stations, and sewage treatment plants is exceeded.

Problems in Developing Urban Areas

As Figure 2 indicates, in undeveloped areas most rainfall soaks into the soil from which it evaporates or penetrates downward to maintain or raise the groundwater table. Stored groundwater slowly drains into lakes and streams, maintaining stream flow in dry periods. When ground surfaces are paved and surface litter is removed, less water enters the soil, groundwater levels drop and dry-weather stream flows decrease. Surface water runoff, on the other hand, increases. Following urban development flood volumes have been observed to increase by one and one-half to two times, and flood peaks by two to five times. These effects are illustrated by Figure 3.

To remove this excess water from urban surfaces, storm drainage systems are installed. When these systems are discharged into local

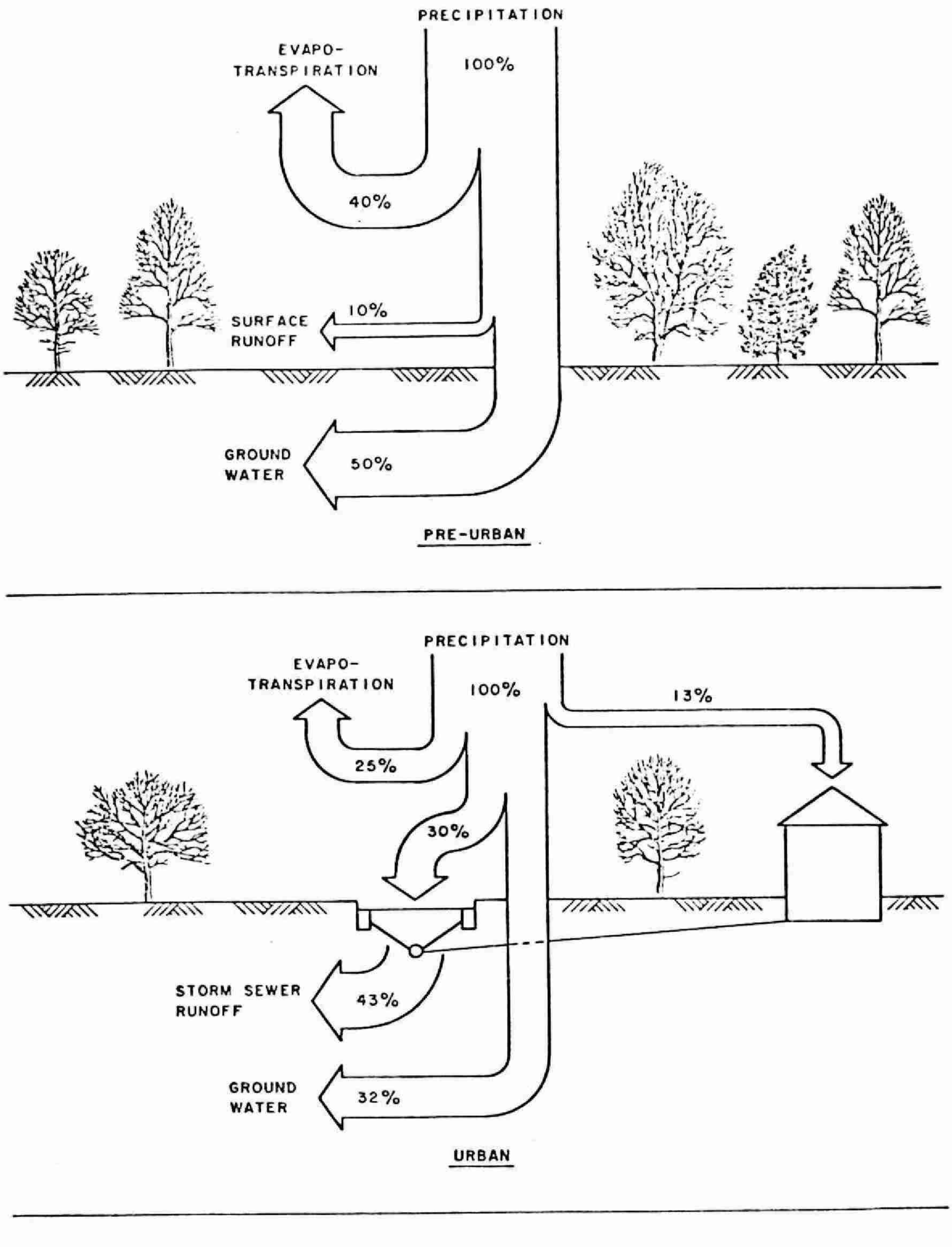
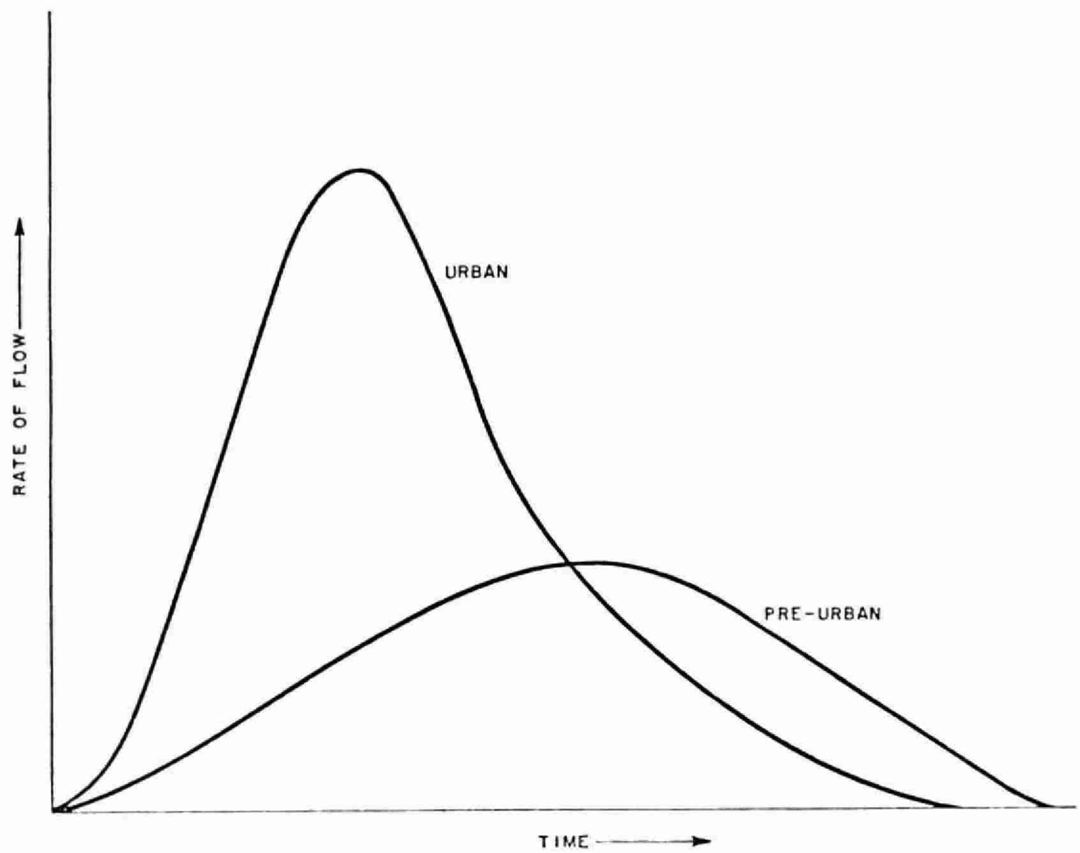


FIGURE 2 : HYDROLOGIC CHANGES RESULTING FROM URBANIZATION (BASED ON VALUES FROM L.B. LEOPOLD, U.S.G.S. CIRCULAR 554, 1968)



URBANIZATION INCREASES PEAK FLOWS AND RUNOFF VOLUMES

FIGURE 3 : EFFECTS OF URBANIZATION ON VOLUME AND RATES OF SURFACE RUNOFF

streams and the capacity of these streams is exceeded, the streams are straightened, widened or enclosed, and the problem is passed downstream. But downstream solutions become more difficult and costly because structures such as bridges and culverts must be enlarged, and because flood plains are occupied by costly structures that must be protected. Not only are local flooding problems solved at the expense of someone downstream; often in the process streams are altered for the worse, and ponds, marshes and other water bodies, which might have been environmental assets, are filled.

The second aspect of drainage problems in developing areas are those related to soil erosion which results when surface cover is stripped and exposed soil is subjected to increased surface runoff rates. The results include loss of valuable soil, turbidity in lakes and streams, and sediment accumulation in lakes, storage basins, and sewage treatment plants. The following values indicate how urbanization may change rates of soil loss (in lb/acre-year) from previously undeveloped land [1, 2, 3, 4]:

Forest land	30 - 600
Cultivated agricultural land	600 - 40,000
Exposed construction site	3,000 - 450,000
Developing urban area	500 - 12,000
Developed urban area	170 - 860

Downstream from developing areas soil losses, and resulting turbidity and sediment accumulations, are caused by channel erosion due to increased stream flows. Increased stream flow may result from increased runoff rates from a tributary basin, or from changes in timing of flood peaks from the basin. Storage on a downstream basin may aggravate peak stream flows if the pre-storage peak from the basin was discharged in advance of peak flows from upstream, and releases from storage were added to these flows.

Water Quality Impacts

Previous sections described the quality of waters discharged from urban drainage systems. This section briefly reviews existing or potential environmental impacts of pollutants contained in urban drainage.

Nutrients effects

Nutrients, particularly phosphorus, produce the same response in aquatic plants as do fertilizers applied to a garden. Algae and other aquatic plants grow in profusion if physical conditions such as temperature and currents are favourable.

Growths of algae and aquatic plants limit the use of lakes and streams for recreational uses and aesthetic enjoyment. In addition, plants contribute to oxygen depletion: although in daylight plants add to the dissolved oxygen supply, at night requirements for plant respiration reduce dissolved oxygen concentrations; and dead plant materials add to the total load of decomposing organic matter.

Oxygen demand effects

Oxygen concentrations in lakes and streams are reduced when oxygen is consumed by bacteria that decompose organic matter. The potential effect of any organic matter is commonly determined by the BOD test, which indicates rates of oxygen consumption by carbon-containing substances. Unoxidized forms of nitrogen (organic nitrogen and ammonia) may impose additional oxygen demands.

When oxygen is consumed faster than the rate at which it can be replaced by natural processes, concentrations in water will drop, and may reach values below which aquatic life is affected. At critical levels fish will be asphyxiated or fish-food organisms eliminated. Under less critical conditions, fish are stressed by reduced dissolved oxygen levels and if other stress factors such as toxic materials or high temperature are present the effects combined can be lethal or severely reduce fish reproduction. In the extreme, when dissolved oxygen is exhausted, the unpleasant effects of anaerobic conditions become evident.

Interrelationships

The following discussion, from a report on the Thames River Basin [5], describes some of the complex interrelationships among factors affecting water quality:

> "In the example, nutrients from urban and rural sources over-fertilize the stream, resulting in profuse growths of

algae and aquatic plants in summer when other conditions are favourable for growth. Excess aquatic plants are unsightly and adversely affect the aesthetics of the water course.

Water quality problems are most severe in summer months when a combination of natural and man made factors magnify adverse water quality effects. Lack of river bank vegetative cover, increases in sunlight energy and excess quantities of plant nutrients provide ideal conditions for aquatic cover and algae growth. The steady build-up of plant biomass is typically accompanied by a steady recession of natural streamflows which magnifies the effects of the biomass, and also provides less water to dilute waste materials continuously discharged from urban and rural areas.

Water temperature increases in summer and causes increased respiration rates of all organisms in the water. At the same time, oxygen saturation values decrease with increasing temperature, so that less oxygen is available in the water for the competing organisms.

The combined meterological, physical, and biological conditions described above can lead to crucial stress conditions for fish life. Symptomatic of extreme stress conditions in the aquatic environment is the sudden localized appearance of large numbers of dead fish."

Sediment effects

Sediments include suspended solids in combined sewage and surface runoff, and soil materials eroded from construction sites and stream channels. Suspended solids in a water-course render the water aesthetically displeasing because of the resultant muddy appearance, and block stream channels, fill reservoirs and can endanger fish. Subsequent deposition of the material can foul the stream bottom and fish spawning beds and smother bottom organisms that support stream productivity. Organic solids from sewage treatment plants, storm sewers, and combined sewers often settle out to form sludge banks in slow moving sections of the river, where they can represent a reservoir of oxygen demand, bacteria, metals, nutrients, and organic chemicals which can affect overlying waters or be swept downstream in storm periods.

Effects of salt

Excessive salt concentrations, which are generally associated with ice control on streets, can impair the value of ground and surface waters for some industrial uses, and cause or increase stratification of lakes and thereby contribute to accelerated eutrophication. High concen-

trations of salt have affected the palatability and even the safety of groundwater supplies. The maximum concentration of sodium (20 mg/l) for persons on low sodium diets is being exceeded in an increasing number of communities in the eastern U.S. as a result of sodium chloride used for highway deicing [6].

Bacteriological effects

Urban storm runoff, treatment plant bypasses, and combined sewer overflows contain bacteria and viruses that can produce a wide variety of diseases and disorders ranging from typhoid and dysentry to skin, eye, ear, nose and throat infections. The potential presence of these organisms is indicated by the presence of coliform and fecal coliform bacteria, which occur with much greater frequency in fecal discharges and are easier to identify. As Table 2 indicates, coliform and fecal coliform counts in storm water discharges may result in closure of swimming areas.

Other effects

Heavy metals and persistent organic substances in combined overflows and surface runoff are potential threats to aquatic organisms and, through accumulation in food chains, to higher organisms.

URBAN DRAINAGE PROBLEMS IN ONTARIO

Ontario Examples

This section is intended to provide examples that indicate the extent and magnitude of urban drainage problems in Ontario communities. It is in no sense a complete list of these problems, because problems in many areas have not been documented. Unless indicated otherwise, the information has been taken from two recent reports: one by the Ontario Ministry of Environment [7], the other prepared for the Urban Drainage Subcommittee by Gore and Storrie Ltd. [8].

Overloaded sewers

Many communities in Ontario have experienced flooding problems due to structural or hydraulic inadequacy of old combined sewers. Communities where such problems have been reported include:

Campbellford	City of Toronto
Chatham	Sarnia
East York	Thunder Bay
London	Wallaceberg
Napanee	Ottawa

Inflow and infiltrations are serious problems in many communities with separate systems, including Kingsville, Leamington, Lincoln, Sault Ste. Marie, Smiths Falls and Thorold. A number of "separate" systems with flooding problems are in fact only partly separated because of interconnections, diversions, and storm water connections.

The Borough of North York provides an example of damage to basement walls and floors as a result of overloaded sewers; many houses in the O'Connors Hills area have been damaged as a result of flooding from surcharged storm sewers [9].

Downstream flooding

Examples of situations where upstream development has created problems are:

- A small drainage ditch in Timmins, which formerly carried approximately 20 cfs, must now accommodate 400 cfs.
- In the Metropolitan Toronto area upstream development, in the period between design and construction of channelization projects, regularly results in design capacity of channels being exceeded in small storms.

Lowered groundwater levels

In Aurora, reduced groundwater levels and base flow in streams have resulted from: reduced groundwater recharge, construction of municipal services, and communal and domestic wells.

Combined Sewer Overflows

Among the communities where pollution resulting from overflows of combined sewage has been recognized are Leaside, St. Thomas, and the Borough of York. Combined sewer problems also exist in the Thames River basin and Great Lakes communities.

Surface runoff

Midland Park Lake, a small (360 ac) recreational lake in the Town of Midland, Simcoe County, represents an example of a small urban lake exposed to the threat of development in its drainage basin. A report by the Ontario Ministry of Environment [10] suggests that if development in the drainage basin is to continue, untreated storm water should not be discharged to the lake. Pollutants of particular concern were phosphorus and bacteria, and potential damage from sediment resulting from construction.

Deterioration of the bacteriological quality of the Rideau River has been attributed to surface runoff following urbanization.

Deicing salts and snow disposal

Chloride levels measured during periods of winter thaw in Black Creek in Metropolitan Toronto exceeded limits for domestic and industrial use and wildlife [11]. Chloride from road salts represent a significant fraction of the total reaching Lake Ontario.

Snow falling on urban roads accumulates contaminants such as oxygen demanding substances, oils, salts, heavy metals, particulate matter such as clay and sand, litter, and often garbage [12], and direct disposal of polluted snow into receiving waters can result in water quality deterioration. Data collected by the Ministry of Environment shows that concentrations of all pollutants are higher in snow collected from more heavily travelled roadways.

Concern about the effect of deicing chemicals, and effects of disposal of polluted snow, has been reflected in the Ministry of Environment Guidelines for storage and application of deicing salts and for snow disposal [12].

Sanitary sewer bypass

A recent study by the Ontario Ministry of the Environment, as part of the Urban Drainage Subcommittee program, has been concerned with defining the magnitude and characteristics of bypasses from several Ontario treatment plants.

Erosion and sedimentation

Many segments of water courses in Metropolitan Toronto exhibit considerable bank instability and require measures to control erosion. Several areas in Oshawa have experienced serious bank erosion resulting in increased sediment loads in streams. Minor stream erosion problems are also reported by the North Grey Conservation Authority.

Thames River Basin

A water management study for the Thames River Basin [5] describes a variety of water quality problems related to urban drainage:

- problems related to suspended solids in storm water and combined sewage overflows;
- bacterial counts increased by combined sewer overflows;
- unrecorded urban runoff, including sewage bypasses during storms, are critical sources of organic wastes from Woodstock, Chatham, Stratford and London;
- even after phosphorus removal to meet Great Lakes standards is achieved, the remaining load, together with inputs from urban runoff, may support troublesome levels of aquatic weed growth;
- 80% of the annual phosphorus contribution from Stratford originates from sewage bypasses, urban runoff, and minor point sources.

Great Lakes

The 1975 Report of the Great Lakes Water Quality Board of the International Joint Commission states: "Combined and storm sewer problems continue to be significant causes of water quality impairment in the 'problem areas' identified in this report".

The report identified two areas in Ontario, Toronto Harbour and Collingwood Harbour, where excessive bacterial counts and algae growth, respectively, are attributed to combined sewer overflows. Other areas where problems are identified and combined overflows occur are Hamilton Harbour and Thunder Bay.

Local effects of urban drainage are exemplified by a study group report on the Toronto Central Waterfront [13]. Sixteen storm water outlets and 25 combined sewer overflows discharge into the Central Waterfront area. High coliform counts in several areas are attributed to combined overflows. Sediment accumulations in the harbour, which are considered to be reservoirs of nutrients, heavy metals, and PCB's originate from the Don River and urban drainage flowing to the harbour. The Toronto Harbour Commission has borne a significant increase in maintenance dredging costs as a result of the developmental activities in the Don River Basin.

Road salt, most of which is drained into storm sewers and stream channels by snowmelt or runoff, accounts for 20 to 40% of the total chloride input into Lake Ontario [14].

On a lake-wide basis, the principal problem to which urban wet-weather sources contribute is accelerated eutrophication resulting from excessive phosphorus loadings. Municipal discharges account for approximately one-third of the total phosphorus discharged to the Great Lakes from Ontario [15]. Wet-weather flows from storm water and combined sewer overflows will, after targets for phosphorus removal of treatment plants are met, account for nearly 40% of municipal phosphorus discharges, i.e., for about 13% of the total phosphorus loads to the lakes from the Province of Ontario.

Cost Implications

One indication of the magnitude of urban drainage problems is the cost associated with their solution. No overall estimate has been made, but the order of magnitude of expected costs may be indicated by the following:

- Approximately 38% of the population of Ontario is served by combined sewers. Many of these sewers are inadequate because of condition or capacity. An indication of replacement cost is an estimated $18,260 per acre (ENR 2000) to separate combined sewerage systems in the United States [16]. Applied at ENR 2500 to the 71,000 acres served by combined sewers in Ontario [17] this corresponds to a total cost of $1.6 billion.

- According to a recent estimate [17] the cost of providing storage and treatment could vary from $0.23 billion for 50 percent control to $0.55 billion for 75 percent control of wet weather pollution in the Great Lakes Basin.

These estimates, which exclude detailed consideration of factors such as required trunk sewer construction and the need for replacement of overloaded storm drainage systems, and the possibility that in some communities alternative approaches may cost less than combined sewer separation, nevertheless suggest that the overall cost of solving flooding and water pollution problems associated with existing urban drainage systems in the Great Lakes Basin will be several billions of dollars.

SUMMARY

Increasing urbanization is accompanied by new drainage problems in developing areas and by aggravation of problems in areas that are already developed. These problems are related to changes in both the quantity and quality of runoff as a result of urbanization. They are reflected in property damage, health hazards, and recreational and environmental impacts. Solutions to these problems will be expensive, but these are real problems that cannot be ignored, and billions of dollars will have to be committed to dealing with them.

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A MUNICIPAL ENGINEER'S VIEW OF URBAN DRAINAGE

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Borough of Etobicoke

When I was first approached with respect to presenting a paper on "A Municipal Engineer's View of Urban Drainage", I thought it would be relatively simple. However, when the topical outlines of the various papers were available, it became apparent that I should avoid conflict and duplication with Paper No. 2 and possibly with Paper No. 6. Consequently, this paper will assume that the previous paper by D.H. Waller will already have outlined the many problems which might be encountered by a municipality in respect to urban drainage, and that a subsequent paper by L.D. House will deal with political, legal and planning aspects of urban drainage.

Based upon the above assumptions, I will attempt to give some idea of the many problems which the Municipality of Etobicoke encountered during the period from 1945 to the present. During this period, urbanization changed a largely rural municipality with a few small scattered hamlets with a total population of approximately 21,000 into a large modern urban community with a population just under 300,000. I should point out that approximately 45,000 of the population increase was due to the amalgamation of the three Lakeshore municipalities of Mimico, New Toronto and Long Branch with the Municipality of Etobicoke. The balance of the increase in population of approximately 234,000 resulted from new development. During the period of peak development, the annual population increase was 10,000 to 12,000.

The Borough of Etobicoke, with a present population of just under 300,000 is one of the six municipalities which comprise the regional municipality of Metropolitan Toronto.

Situated as it is on the shores of Lake Ontario, it has an area of approximately 49 square miles with a frontage on Lake Ontario of approximately 4 1/2 miles, extending approximately 11 miles inland, and generally sloping from northwest to southeast towards the lake.

Four major watercourses drain surface runoff to Lake Ontario. A network of lesser streams drain into these major streams or directly

into Lake Ontario. Because these four major watercourses and their subsidiaries had a fair gradient, Etobicoke deemed itself fortunate as compared with extremely level municipalities such as Essex County or on the Prairies. Later in this paper, I will indicate that the presence of these selfsame watercourses lulled the municipality into a false sense of security with respect to storm sewer systems.

Soil conditions vary considerably across the municipality but generally it can be said that in most areas the soil is of a clay or clay loam nature to a depth of four to twelve or fifteen feet. Below the clay overburden lies an essentially impervious shale, in many cases, weathered to a depth of six to twenty-four inches. While generally the soil could be described as clay, overlying shale, there are two relatively small areas of the municipality where the soil is predominately sand - one "our wet sand area" with a high water table near the surface, and one "our dry sand area" where the water table for most, if not all of the year, is well below not only the foundations of the buildings but also below the usual depth of the sewerage systems.

The task assigned to me at this conference is to give a general summary of the urban drainage problems which have been experienced by municipalities over the years and how the municipality has coped, or attempted to cope, with these problems. I don't really know why I was selected for this task but I like to think it is not because the Borough of Etobicoke has more drainage problems than other municipalities. Undoubtedly Etobicoke has experienced its share of urban drainage problems over the years - problems related to soil conditions; to poor sewer construction; to poor building construction; to poor sewer design (by modern day standards); to the vagaries of our climate; and to a host of other reasons of less importance.

It is my opinion that Etobicoke has indeed coped with these many problems in a satisfactory manner and in accordance with generally accepted good engineering practice. I am of the opinion that Etobicoke has also been very progressive in its utilization of new methods and equipment to handle or solve these problems.

Etobicoke's urban drainage problems seem to divide into two distinct divisions - those related to the area along Lake Ontario which

was developed some 40 or 50 odd years ago and those related to the post World War II period of rapid urbanization of what was essentially a rural area.

It seems that Etobicoke and other municipalities may very well enter a new period of urban drainage problems as a result of the high cost of housing in the Metropolitan Toronto and other areas. The Borough of Etobicoke over the years strove to ensure that residential development provided the amenities, the open areas, the building setbacks, the street aesthetics etc., to enable the occupants to enjoy a reasonable standard of living and their own property and their community. The uncontrolled spiralling cost of land, and to a lesser extent services for housing, is leading (I deliberately do not use the word forcing) the developers and planners to talk of reduced road widths, reduced building setbacks, reduced services etc., in housing developments. In brief, the indication is that as much housing as possible will be crammed and jammed onto each parcel of land with as few services such as sidewalks, storm sewers etc., as possible. I am not saying that there is not a need for improvement or change in order to reduce housing costs. I am, however, genuinely concerned at the possibility of radical changes which will be a retrograde step in housing development and could very well lead, not to lower housing costs, but higher ultimate capital, maintenance and municipal operating costs as well as increased and serious drainage problems, not to mention a deterioration in the quality of properties and neighborhoods.

I am sure that many of you must be wondering if I will ever get around to outlining the urban drainage problems encountered in Etobicoke and what Etobicoke has done to cope with these problems. Last but not least I presume you are also interested in our success in coping with the drainage problems. I make no apology for the long preamble but I felt it necessary to "set the stage" before tackling my assignment in detail.

The previous speaker has outlined in general terms a number of drainage problems which have been or might be encountered by an urban municipality. Without having seen the contents of his paper, I have a hunch that Etobiocke has probably experienced all of them plus perhaps a few more which he has overlooked. I have a hunch that many other municipalities have also experienced most of the same problems.

It is difficult to know where to start on my topic but after some thought, it seemed to me that Etobicoke's urban drainage problems are related to a number of different eras in the history of Etobicoke and this is possibly true of most municipalities.

All the sewerage systems in Etobicoke were and are designed as separate systems and there are no sewerage systems which were deliberately designed as a combined system. I suppose I should immediately qualify that statement by saying that obviously the sanitary sewer systems were designed to handle a certain amount of groundwater infiltration but certainly were not designed to handle any surface water conducted either directly or indirectly to the system. Therefore an outline of Etobicoke's problems will not cover the problems related to sewers designed as combined sewers.

In each of the areas of Etobicoke which were formerly small incorporated and unincorporated villages and towns, which have been engulfed by the spreading metropolis of Toronto, the drainage problems seem to relate mainly to old sewerage systems which are, in many cases, inadequate in depth, inadequate in size, inadequate in construction and materials and finally inadequate in design by modern day standards.

Up until fairly recently, the urban drainage problems which were of concern, could be summed up in one word - <u>flooding</u>. Flooding in turn could be divided into two categories: flooding of homes and basements, which was a serious problem, and surface flooding which was a nuisance problem.

As of more recent years, we are aware of a second urban drainage problem - namely <u>pollution</u>.

In the past, it has been a generally accepted practice to discharge storm sewers to the closest stream or lake. It is becoming increasingly evident that such indiscriminate discharge of storm sewers to adjacent streams is creating or will create urban drainage <u>erosion</u> problems on the receiving streams. Often such erosion problems require expensive remedial works.

The high cost of housing and servicing for housing is creating municipal <u>financing</u> problems.

One cannot deal with urban drainage problems without realizing that the problems relate, not only to surface drainage and storm sewers, but are interrelated and intertwined inextricably with combined sewers and sanitary sewers.

I will deal with the problems in the same order in which I have listed them above.

Etobicoke, as has any other municipality, encountered isolated problems of sanitary sewage backup into private homes from time to time. Always these situations become emergencies. Rush investigation of such isolated flooding cases almost invariably disclosed a private sewer connection or a main sewer blocked by roots or solid matter, or a partially or completely collapsed sewer.

After a period of dealing with each such "emergency" flooding with the "time honoured" bucket cleaning equipment, it was decided to embark on a preventative maintenance program. I might say that Etobicoke was one of the first Canadian municipalities to establish a complete preventative maintenance program for the sewerage systems where every sewer was "inspected" and cleaned if necessary every three months to ten years on a regularly scheduled basis. The term "inspected" is used very loosely since visual inspection was virtually impossible prior to the development of suitable photographic equipment for sewer inspection. The periods between inspection and cleaning was established on the basis of the conditions found at the time of the last cleaning. I believe that most municipalities now have a sewer preventative maintenance program. In case there are some without such a program, I would like to say that I cannot speak too highly of the benefits of such a program. Without doubt, the benefits of the preventative program in Etobicoke, in my opinion, warrant the expenditures involved.

With the advent of advanced photography Etobicoke was one of the first to add a still camera for taking photographs of the interior of the sewers. What these pictures disclosed was astounding to us. Often the condition of the sewer, with deteriorated pipes, offset joints, massive roots and atrocious practices in connecting laterals to the main sewer, was enough to make any designer or operator of a sewerage system shudder. Laterals often projected into the sewer and in some cases a

quarter or a third of the diameter of the sewer. Laterals which projected into the sewer presented problems to the sewer inspection and cleaning equipment. Also the equipment often broke the projecting laterals presenting new problems. A former plumbing inspector for Etobicoke was much concerned with the problem and developed a saddle to improve the connection of laterals to an existing sewer. As a matter of fact when no established company was interested in producing the saddles, he left the municipality to form his own company that went on to become a highly successful supplier of sewer pipe and sewer pipe accessories.

Perfection of TV cameras for inspection of the pipe was a further improvement on the techniques for ascertaining what was happening in and to those buried sewer pipes and to determine exactly what were the causes of the isolated flooding cases. Obviously they were also a valuable piece of equipment for carrying out preventative maintenance programs.

I have dealt in a cursory fashion with the problems of the isolated flooding of houses due to a blocked sewer and how Etobicoke tackled the problem. Certainly the establishment of a planned, scheduled preventative sewer maintenance program was a real step forward, and certainly the development of cameras and TV equipment for inspecting sewers not only provided a much needed tool for inspecting underground utilities, but also eliminated a great deal of the guesswork formerly associated with solving urban drainage problems relating to blocked or overloaded sewers.

Sewerage systems were designed in accordance with the accepted practices and design formula in use at the time, but one of the most difficult tasks was to ascertain what the actual flow was in the sewers and how it varied at certain times of the day and under different climatic conditions. Spot observations of the depth of flow of sewage in the sewers, even with the most elaborate of planned programs, was not only difficult but expensive if properly done, and the results were in many cases very incomplete. A more accurate method of measuring the flow in sewers seemed necessary and Etobicoke purchased a number of portable continuously recording sewer gauges. This equipment has proven invaluable in assessing the flow in the sewers. A most valuable "tool" which, in

my opinion, every municipality should include in its equipment. Again I believe Etobicoke was one of the first Canadian municipalities to purchase such equipment and carry out a planned flow monitoring program.

I will now deal with the operating problems due to floodings which were not isolated cases but more widespread in the municipality. Invariably these were related to periods of intense rainfall or periods of prolonged rainfall.

There are some eight or ten dates indelibly etched in my mind. They relate to such periods of intense or prolonged rainfalls when backup of the sanitary sewers in a number of areas of the municipality caused the municipal switchboard to "light up" like the proverbial Christmas tree. Irate ratepayers were asking "why" and demanding immediate action.

The answers were not simple or quickly available. In many if not most cases, it involved a long, tedious investigative procedure. Obviously the sanitary sewers were inadequate to handle the flow reaching them causing them to overload, back up and flood back into private properties. Was it inadequate design? Was it water reaching the sanitary sewerage system which should not be reaching it? If so, how did it get there?

The long tedious investigations to which I referred earlier, usually disclosed the causes to be many. Obviously, however, the overloadings were at least partially connected with urban drainage in some manner since they occurred during heavy rainstorms. Without going into details, I will enumerate a number of situations which Etobicoke found to be causes of the overloading of the sanitary sewerage system. For ease of reading, I will give these in a tabular form. Each of the floodings and sewer backups in Etobicoke resulted from several of the following situations, although each of the sewer overloadings was not always the result of the same combination of situations.

1. Partial blockage of sewer due to roots or partial collapse;
2. Extra heavy flow from foundation seepers connected to the sanitary sewer;
3. Homeowners solving surface drainage problems by illegally connecting catch basins or eavestrough downpipes to the

sanitary sewers or more often to the foundation weepers and then into the sanitary sewer;

4. Occasional error in connection of storm sewer catch basins to the sanitary sewer instead of the storm sewer;

5.(a) Lot elevations sloping toward houses and drainage finding its way into foundation weepers, which in turn discharged into the sanitary sewers;

(b) Settlement of backfill around houses, which also resulted in surface drainage reaching the foundation weepers;

(c) Eavestrough downpipes discharging immediately adjacent to building and percolating rapidly down to the foundation weepers and thus into sanitary sewers;

6. Roads flooded over the ponded areas over perforated sanitary sewer manhole covers;

7. In one area a former works superintendent had permitted and even advised home, commercial and industrial property owners to connect roof water to sanitary sewers which were not designed to take flow, "in order to flush out the sewers";

8. Sewers installed some years ago to lower design standards were standard practice prior to the advent of automatic dishwashers and washing machines.

In order to check for sources of extra water entering sanitary sewers, it meant detailed inspections of each and every house in the area, as well as dye-testing in many cases to check eavestrough downpipes which disappeared into the ground to ascertain where they discharged.

Owners of property with illegal connections to the sanitary sewers were required (wherever possible and feasible) to disconnect some. In many cases such disconnection was virtually impossible without creating other more serious problems.

The municipality, in some cases, was faced with expensive supplementary or interceptor sanitary sewers to reduce the chance of further sewer overloading. Where necessary such interceptors were installed to give some assurance to the householders that they would be no more prone to repeated sewer backups than any other area of the municipality.

Usually temporary relief was provided by overflows to adjacent streams or Lake Ontario until such time as a permanent solution was found. Etobicoke thus found itself with some "combined sewers with overflows" even though the sewers were not actually designed as combined sewers.

Turning now to surface water and sewers designed as storm sewers, I will outline a few of the problems encountered by Etobicoke.

Other than a shortage of water in the taps or a sewer backing up into the basement, probably one of the most aggravating problems faced by a property owner, and particularly a residential property owner, is a problem of rear yard drainage. It is an even more serious problem where the rear yard drainage finds its way into the building.

Usually the cause of this problem is a building set at an improper elevation in relationship to the road or the rear yard. For many years this was a very common problem, due without question to inattention to detail of lot grades by the architect or builder. The Borough tried to eliminate it by requiring all developers to file a lot drainage plan. This has alleviated the problem to a very large extent but has not solved it.

One minor perhaps but annoying urban drainage problem occurs when rear yard drainage is blocked due to construction of fences, landscaping, pools, patios, etc., by one property owner causing ponding on a neighbour's property. I never realized how many neighbour "squabbles" there were due to drainage problems until I became a municipal engineer. As yet the Borough has been unable to find a good solution to this problem.

In respect to surface drainage, particularly in relationship to the public roads, Etobicoke has for many years attempted to give special attention to road design to ensure that road gradients are continuous if at all possible. Hopefully, since it is not economically feasible to design storm sewers to handle the maximum rainfall, the road gutters will accommodate the excess flow and such gutters will discharge to a stream or lake without causing serious flooding of the road. Close attention to road gradients is essential in design of storm sewers. In Etobicoke where continuous road gradients are just not possible and low areas on the public

road cannot be avoided and private property could be flooded, special attention is necessary with respect to surface drainage. Many years ago, Etobicoke adopted a policy in such cases which has avoided serious flooding problems from this cause. In these cases the Municipality has wherever possible (and this seems to be at least 95% of the time) designed or required an overflow depression on easement across private or public lands. This overflow depression permitted excess flow to reach a river, or the lake, or another road with a continuous gradient to a natural outlet without causing undue ponding on the road or flooding of private property. I understand from recent meetings that many municipalities have not been providing such overflow depressions and consequently are experiencing problems which Etobicoke has been able to avoid in almost all recent developments. Many a time Etobicoke has been spared serious flooding by reason of the presence of such an overflow.

In recent years, as the watersheds of the four major watercourses in Etobicoke became more and more developed, the erosion problems on these streams began to accelerate. With the escalation of this erosion problem, it became painfully evident that remedial works to control such erosion was not only costly but detracted from the aesthetics of the streams and valleys.

With escalation of erosion on the streams, Etobicoke began to look more closely at the time-honoured (but now dishonoured) practice of piping surface water to the nearest stream or lake without regard to the effects on the stream flow. Some slight progress was made by Etobicoke in getting industry to design their roofs to pond rainfall on the roof and discharge at a controlled rate. However, little progress was made on controlled runoff from parking areas or large institutional buildings or constructing holding reservoirs under shopping centre parking lots.

The Municipality did investigate at least five possible storm sewer reservoirs with controlled discharge including the use of abandoned shale pits. In each case the use of such reservoirs was deemed impractical. I'm not sure that the same studies carried out today would necessarily result in the same conclusions.

In a fully developed or almost fully developed urban area, the shortage of available space for reservoirs, the cost of land or the cost

of building reservoirs or ponds on existing parking lots or landscaped areas makes this solution much more difficult than when achieved during development of new areas.

Etobicoke is currently giving serious consideration to enactment of by-laws pertaining to controlled surface water runoff from institutions, commercial and industrial developments with large impervious roofs, and parking areas.

Certainly the philosophy of Etobicoke is changing rapidly in respect to discharge of storm water to the nearest stream or lake. It is evident to the Engineering Department that it is not only practical and economically feasible but necessary to design for controlled discharge of storm water to streams. In this field, Etobicoke has made a little progress but hopefully with an increasing awareness of the need for controlled storm water discharge and as a result of recent discussions and conferences such as this one, Etobicoke and other municipalities will become more involved in this aspect of administering urban drainage. It is my opinion that Etobicoke (and many other municipalities) are not moving nearly fast enough with respect to controlled storm water discharge.

I have covered, in a somewhat incomplete manner, the urban drainage problems of flooding and erosion and would like to now turn to the urban drainage problem of pollution.

Certainly trade waste discharge to the sanitary sewerage system in Etobicoke has caused problems in the sewers and at Metropolitan Toronto pollution control plants, and continual surveillance is necessary to keep this under control.

In this chemical age in which we live, the pollution problems become even more complicated. I refer of course to radioactive wastes, and the many chemical compounds used in medical tests and treatments and by industrial firms which end up as wastes discharged to the sanitary sewers without any consideration as to their effect on the sewers or pollution control plants. Such discharges often are not readily distinguishable and most often the operator of the sewerage system has no knowledge of them. Etobicoke has even encountered cases of individuals operating a small chemical manufacturing business in their residence basement with discharge to the sewerage system and of amateur chemists "fooling around at home".

Pollution problems resulting from urban drainage in Etobicoke have taken many forms and it is hard to know where to start. Surreptitious dumping of contents of trailer holding tanks, used automotive lubricating oil, painting cleanup materials, etc., into roadside ditches, catch basins or streams, while not a prevalent practice, did occur to the extent that some action was necessary. The Borough installed two tanks for receiving used lubricating oil from "do it yourself mechanics". This was publicized and did receive usage from the public. The Borough also installed station where trailer sewage holding tanks could be discharged to the sanitary sewers. This also was advertized and received limited usage.

I will not dwell on the problems related to accidental spills of inflammable, toxic or objectional materials which reach the road ditches, storm sewers or streams due to highway accidents or accidental or negligent spills on industrial properties. These are familiar to everyone. Suffice it to say that Metropolitan Toronto and the area municipalities comprising Metropolitan Toronto have cooperated and coordinated their efforts with the Province to deal with such emergencies. It is my opinion that the policies and procedures with respect to spills are fairly effective in Toronto.

Etobicoke has had several cases where storm water from industrial areas has carried chemicals which completely corroded away the concrete sewer pipes. In one case the invert of the pipe was completely corroded away by the liquid wastes and the obvert completely corroded away by the gaseous fumes.

With more complete and comprehensive surveillance of industries by both Etobicoke and Metropolitan Toronto, this problem is nowhere near as serious as it once was.

It is my observation that today there are a considerable number of our citizens who are very much aware of and concerned about the pollution of our streams. Since we cannot carry out continuous surveillance of all our ditches and watercourses, Etobicoke welcomes and encourages its citizens to watch for and report evidence of pollution. In this way, the Borough believes it is more apt to get early information on such pollution and thus has a much better opportunity to determine the source of the pollution.

Pollution from winter salting operations on our roads and streets is an urban drainage problem familiar to all of us I am sure. The solution to it is still not known but certainly it is evident that the average resident of Toronto is more concerned with having his automobile "mobile" with a certain degree of safety during snowy, icy or sleeting weather conditions than he is in stopping pollution of our lakes and rivers.

One of the urban drainage problems which was listed earlier in this paper related to financing. I have not touched on this particular problem since I understand this aspect will be covered in some detail by Mr. L.D. House in his paper entitled "Political Aspects of Urban Drainage". Nor have I discussed the problem of road and stream pollution during housing, road, utility or other construction since Mr. J.J. Armstrong's paper on Wednesday will go into some detail on "Erosion Control Methods during Construction". I would, however, like to say that in the past control of this aspect of urban drainage has been difficult. Certainly Etobicoke is giving this drainage problem much greater attention than it has in the past and hopefully this attention will pay dividends in the future.

We are all familiar with the normal problems of decaying vegetation, etc., in catch basin sumps. More recently, numerous press articles on the proliferation of pets in cities and problems of disposal of pet feces has alerted us to the urban drainage pollution problems caused by pets.

I haven't said anything about urban drainage pollution due to fall-out from smokestacks, industrial plant vents and automotive exhaust gases. There is a very good reason for this omission, namely, I haven't any idea how serious a problem it is and secondly I have not found any literature on the subject which really assesses the problem.

One of the most glaring urban drainage problems until recently was the lack of knowledge or research into the extent and/or duration of pollutants in storm water runoff. I know that personally I always felt that it was negligible and only lasted for a short time at the beginning of any moderate or heavy rainfall. I have a hunch that many other engineers shared my feelings. Certainly recent research is proving this to be a fallacy.

Until I started to prepare this paper I never realized that Etobicoke had so many drainage problems which I and my staff were called upon to solve on a day to day basis. I guess one tackles each as it comes along and tries to solve them on a temporary basis while working out a long-term permanent solution.

I haven't touched on such mundane urban drainage problems as proper grate design to intercept gutter flow on steep road gradients or catch basin grate design that is compatible with curbside bicycle travel.

Hopefully the observations in this paper will accomplish what the organizers of this urban drainage conference hoped would be accomplished. I have a feeling that what I have said is well known to most urban municipal engineers who have been in the business any length of time. Hopefully also it will bring to the attention of some less experienced municipal engineers some of the things they should be considering, and also it will help consulting engineers, educators and others to a better understanding of the problems of a municipal engineer responsible for operating an urban drainage system.

At the risk of insulting the consulting engineers, I have always said the difference between a municipal engineer and a consulting engineer is that the municipal engineer has to live with the errors in design of the product. Fortunately, I am very pleased to see more and more consulting engineers keeping in touch with the municipalities to determine the problems and shortcomings of their designs in order to assist in remedial action and to do a better design on future projects. Personally, I am a firm believer that there is no better teacher than practical experience in operating the drainage system. One of my biggest problems is to get the "feed-back" from the supervisors and superintendents in the field.

In conclusion, I will only say that I personally believe that we still have a long way to go to adequately handle and administer the drainage in an urban area.

WATER QUALITY ASPECTS OF URBAN RUNOFF

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INTRODUCTION

It is recognized that urban runoff contains environmental contaminants which pollute or could pollute the surface waters of Ontario. The trend towards continued urbanization, resulting in greater concentrations of industrial, commercial and residential land uses in Southern Ontario, will tend to aggravate the existing pollution problems in local watercourses and the Great Lakes. The greater population, along with the trend towards more leisure time, will increase demands for water-based recreation and provide impetus for pollution control measures. These control measures will be based on considerations of the specific water quality problems and the effectiveness of the control measure in preventing or remedying the problem. Planning for preventative and remedial measures requires an understanding of the causes of runoff pollution, the magnitude of the pollution and its effect upon receiving waters.

The magnitude and rate of pollutant emissions in urban runoff are dependent on the complex interactions between land use, pollutant accumulation, drainage system configuration, the characteristics of the precipitation or snowmelt event and time factors such as season or length of time since the previous storm. The effect of the pollutant emissions on receiving waters depends on the magnitude and rate of the pollutant runoff event or series of events, and the characteristics and uses of the receiving water. In order to evaluate the effect of urban runoff on receiving waters, it is necessary to identify both the runoff pollution characteristics and the receiving water characteristics and establish a cause and effect relationship between the two. The identification of an existing or potential adverse effect on the water environment from urban runoff, coupled with the objective of maintaining water quality for beneficial uses, provides justification for action to remedy or prevent problems.

It is the purpose of this paper to outline applicable environmental objectives established by government agencies for controlling urban runoff pollution, to outline the sources and pathways of pollution in urban runoff, to describe the characteristics of urban runoff pollutants in general and as measured in urban test catchments in Ontario, to examine the magnitude of urban runoff pollutant loads in Ontario and finally, to indicate the effects of urban runoff upon receiving waters.

WATER QUALITY OBJECTIVES

The basic philosophy or goal of the Ontario Ministry of the Environment is to maintain environmental quality for beneficial uses and to protect and enhance quality in areas where higher quality than minimum levels is justified. In addition, recent environmental assessment legislation in Ontario incorporates the philosophy of preserving quality by requiring proponents of large-scale projects to assess the impact of their activity on the environment and to control or limit the negative effects.

Concepts for application of these objectives are described in a publication of the Ontario Ministry of the Environment entitled "Guidelines and Criteria for Water Quality Management in Ontario" [1]. These guidelines are summarized below:

i) The water resources of Ontario must meet many needs, some of which are in conflict. The best interests of the people of Ontario require the preservation and restoration of the quality of our water for the greatest number of uses.

ii) For each water use, there are certain water quality characteristics, identified as criteria, which should be met to ensure that the water is suitable for that use.

iii) Water quality standards will be established for the waters of drainage basins based on the important water uses of the basin and the appropriate criteria.

iv) Water of higher quality than that required by the standards will be maintained at that higher quality.

v) All wastes, prior to discharge to any receiving watercourse, must receive the best practicable treatment or control.

The Guidelines recognize that the assimilation and dilution of treated waste effluents is a legitimate use of water provided that other uses are taken into consideration. Specific criteria are provided for the following water uses:

- public drinking water supply,
- industrial water supply
- agricultural water supply,
- recreation,
- aesthetic enjoyment,
- propagation of fish and wildlife.

The application of water quality criteria to the Great Lakes is outlined below:

In 1972, following recommendations of the International Joint Commission, the Government of Canada and the Government of the United States signed an Agreement on Great Lakes water quality. The primary emphasis of the Agreement was to clean up existing pollution problems in the Great Lakes. The Agreement also calls for prevention of further pollution owing to population growth, resource development, and increasing use of water. The Great Lakes Water Quality Board in its 1974 report [2] drew attention to this provision and emphasized the need for effective water quality related land use planning to meet the needs of future growth and development, consistent with the achievement of the water quality objectives.

As part of the Agreement, the following general water quality objectives for the boundary waters of the Great Lakes System were adopted. These waters should be:

(a) Free from substances that enter the waters as a result of human activity and that will settle to form putrescent or otherwise objectionable sludge deposits, or that will adversely affect aquatic life or waterfowl;

(b) Free from floating debris, oil, scum and other floating materials entering the waters as a result of human activity in amounts sufficient to be unsightly or deleterious;

(c) Free from materials entering the waters as a result of human activity producing colour, odour or other conditions in such a degree as to create a nuisance;

(d) Free from substances entering the waters as a result of human activity in concentrations that are toxic or harmful to human, animal or aquatic life;

(e) Free from nutrients entering the waters as a result of human activity in concentrations that create nuisance growths of aquatic weeds and algae.

SOURCES OF URBAN RUNOFF POLLUTANTS

Pollutants accumulate on urban land surfaces and are washed off by rainfall and snowmelt. The characterization and accumulation of pollutant materials are summarized below [3, 5, 31].

Material accumulated on street surfaces is thought to be the major contributor to urban runoff pollution. Material from pervious surfaces generally makes its way to the sewer system over street surfaces. Some of the processes that lead to accumulation of material on street surfaces would also apply to other surfaces such as roofs and pervious areas; however, this discussion will be limited to street surfaces only. The sources of the contaminants are discussed below:

a) Pavement - Erosion, wear and tear of cement and asphalt road surfaces contributes to the accumulation of material.

b) Motor Vehicles - The accumulation of material is correlated to the intensity of vehicular traffic from a variety of causes, thought to include:

- leakage of fuel, lubricants and coolants,
- particles worn off tires, clutch and brake linings,
- particulate exhaust emissions,
- rust and undercoating corrosion products.

c) Atmospheric Fallout - Contaminants from atmospheric fallout and in precipitation contribute to the pollution of urban runoff. A study of bulk precipitation (dry fallout plus rainfall plus snowfall) in seven locations around Lake Ontario provided precipitation chemistry and fallout deposition rates [4]. Table 1 lists the arithmetic mean concentrations of

TABLE 1. BULK PRECIPITATION CHEMISTRY

Arithmetic mean concentrations and ranges by station - 1970-1971, April to November.

Parameter (mg/l)	Toronto Island	Hamilton	Woodbridge	Ancaster	Kingston Airport	Trenton	Main Duck Island
Total phosphorus as P	0.059	0.037	0.035	0.159	0.046	0.038	0.103
Ranges	0.003-0.203	0.008-0.112	0.002-0.082	0.012-0.548	0.004-0.128	0.006-0.161	0.008-0.322
Reactive orthophosphate as P	0.018	0.012	0.019	0.082	0.013	0.012	0.055
Ranges	0.001-0.073	0.001-0.035	0.002-0.082	0.000-0.322	0.001-0.111	0.001-0.089	0.001-0.129
Nitrate+nitrite as N	1.67	1.45	1.24	1.06	0.99	1.31	0.91
Ranges	0.60-4.30	0.63-4.10	0.50-2.90	0.65-1.70	0.43-2.25	0.65-3.40	0.50-1.75
Ammonia as N	0.47	0.61	0.60	0.96	0.46	0.35	0.67
Ranges	0.04-1.30	0.26-1.40	0.02-1.80	0.08-2.70	0.03-1.08	0.05-0.90	0.06-1.28
Sodium	2.98	3.08	1.75	2.26	2.34	2.15	1.80
Ranges	0.75-10.77	0.55-9.36	0.40-4.80	0.45-5.96	0.60-5.51	0.65-4.30	0.52-5.10
Potassium	0.52	0.37	0.84	0.51	0.44	0.74	0.64
Ranges	0.18-1.77	0.15-0.87	0.14-5.75	0.15-1.34	0.18-1.43	0.25-4.20	0.22-1.42
Calcium	6.47	7.04	4.30	4.50	3.83	4.36	3.51
Ranges	2.00-18.00	3.00-15.00	1.00-9.30	1.00-9.50	1.50-8.00	1.10-8.80	1.10-6.80
Magnesium	0.93	1.11	0.75	0.88	0.48	0.43	0.52
Ranges	0.40-2.20	0.60-2.50	0.20-1.80	0.20-1.70	0.10-0.90	0.0-1.10	0.10-1.00
Chloride	1.76	1.19	1.04	0.84	0.73	0.94	0.77
Ranges	0.40-7.70	0.40-4.50	0.30-4.70	0.30-1.60	0.30-1.84	0.20-1.58	0.20-1.50
Sulphate	12.45	11.77	8.80	10.06	6.58	7.95	6.60
Ranges	3.40-28.50	2.20-24.20	1.40-24.10	2.00-20.50	0.50-12.00	2.90-15.00	0.70-10.20
Lead	0.040	0.028	0.039	0.017	0.007	0.007	0.007
Ranges	0.002-0.360	0.002-0.168	0.0-0.260	0.0-0.076	0.0-0.024	0.0-0.016	0.001-0.018
Iron	0.048	0.032	0.029	0.035	0.017	0.010	0.027
Ranges	0.004-0.170	0.004-0.110	0.004-0.220	0.001-0.100	0.004-0.048	0.005-0.040	0.006-0.111
Zinc	0.065	0.104	0.066	0.120	0.052	0.060	0.114
Ranges	0.012-0.160	0.012-0.173	0.018-0.176	0.024-0.300	0.012-0.152	0.014-0.176	0.038-0.262
Copper	0.006	0.009	0.005	0.005	0.005	0.006	0.009
Ranges	0.004-0.008	0.002-0.048	0.001-0.012	0.002-0.016	0.001-0.010	0.002-0.012	0.002-0.016
Cadmium	0.002	0.001	0.001	0.002	0.001	0.001	0.002
Ranges	0.0-0.008	0.0-0.003	0.0-0.008	0.0-0.003	0.0-0.003	0.0-0.004	0.0-0.012
Nickel	0.006	0.005	0.004	0.003	0.003	0.004	0.004
Ranges	0.002-0.022	0.001-0.014	0.002-0.008	0.001-0.004	0.002-0.005	0.0-0.011	0.001-0.010

precipitation for various parameters on a station to station basis for the period January 1970 to December 1971. The table has been set up such that going from right to left the sampling stations are located in increasingly developed, urbanized areas. Table 2 presents the mean monthly areal deposition rates, based on the seven stations in Table 1, for winter and summer months.

TABLE 2. MONTHLY AREAL DEPOSITION RATES - SEVEN STATION SUMMARY [4]

Parameter	January to December		April to November	
	Mean ($mg/m^2/month$)	Median ($mg/m^2/month$)	Mean ($mg/m^2/month$)	Median ($mg/m^2/month$)
Total phosphorus as P	2.98	1.10	3.90	1.57
Reactive orthophosphate as P	1.43	0.19	1.92	0.29
Nitrate + nitrite as N	55.16	53.13	58.07	55.25
Ammonia as N	29.00	18.86	34.73	21.00
Sodium	106.12	93.50	105.42	95.80
Potassium	25.90	17.60	29.83	19.82
Calcium	216.26	201.07	229.57	212.28
Magnesium	34.16	31.25	33.57	31.88
Chloride	63.12	40.18	50.04	40.36
Sulphate	431.25	394.82	438.59	400.04
Lead	1.08	0.35	1.22	0.36
Iron	1.71	1.05	1.59	1.06
Zinc	4.21	3.33	4.61	3.71
Copper	0.33	0.22	0.37	0.24
Cadmium	0.07	0.05	0.07	0.05
Nickel	0.17	0.14	0.20	0.14

d) Vegetation - This includes leaves and other plant materials which fall directly, are blown or are placed directly on street surfaces. There is a marked seasonal variation in the accumulation rates from leaf fall, with a large proportion occurring in the late autumn.

e) Runoff from Adjacent Areas - Vegetation, sediments and soluble salts are washed onto street surfaces by runoff and deposited or evaporated there for washoff in later storm events. Erosion of adjacent areas is dependent on the type of soil, slope, and vegetative cover, and is greatly increased during construction activity.

f) Litter - This includes all materials placed on road surfaces by man and man's pets and includes many products and their packages of the North American consumer society. Bird and pet droppings are thought to be a prime source of bacterial populations measured in runoff.

g) Spills - This includes accidental (and sometimes non-accidental) instantaneous deposits of bulk material often as a convenient (and illegal) disposal method. The occurrence of spills is impossible to quantify.

h) Anti-Skid and De-icing Compounds - The application of anti-skid compounds (sand and grit) and de-icing compounds (sodium chloride, calcium chloride) in winter is a common practice in urban and rural roads. The application frequency and rate is generally dependent on the volume of traffic and the amount of snow. Application rates (related to population density) for Ontario are shown in Table 3 [5].

TABLE 3. SALTING RATES USED IN ONTARIO [5]

Population Density (persons/sq. mi.)	Rate of Application (lb/application/lane mile)
Less than 1000	75 - 800
1000 to 5000	350 - 1800
5000+	400 - 1200

i) Snow Quality - Snow and ice on and near roads tend to accumulate the same materials that would accumulate directly on road surfaces. Table 4 presents quality constituents measured in snow collected from various locations in the Ottawa area [10].

ACCUMULATION AND WASHOFF OF CONTAMINANTS

It has been assumued that a relatively constant rate of contaminant pollution is offset by street sweeping and washoff from runoff events [3]. It is also assumed that the build up of pollutants on road surfaces approaches a maximum in the absence of rainfall or sweeping, due to processes of resuspension and redistribution caused by wind and traffic. These processes are shown in Figure 1 for a hypothetical case including street sweeping and washoff events.

The accumulation rates are generally given in units of pounds of dust and dirt per curb mile or per unit area. It is often assumed as well that pollutant concentrations are related in a fixed ratio to each other, based on data collected in Chicago. The loading rates and washoff phenomena described above are simulated in the urban runoff models STORM

TABLE 4. POLLUTANTS AND POLLUTANT LEVELS FOUND IN SNOW DEPOSITS

Pollutant Concentrations, mg/l (or mg/kg snow)

Pollutant	Location	Undisturbed Snow	Windows Adjacent to Street	Snow Disposal Sites	Disposal Site Runoff	Storm Sewer Runoff
Suspended Solids	-	-		-	96 mg/l	-
	Arterial street	-	3,570 mg/kg	-	-	-
	Collectors	-	1,920-4,020 mg/kg	-	-	-
	Local	-	1,215-2,530 mg/kg	-	-	-
	Parking lot	-	1,620 mg/kg	-	-	-
BOD_5	-	-	-	108 mg/l (mean)	-	-
	Arterial street	-	16.6 mg/kg	-	-	-
	Collectors	-	13.2 mg/kg	-	-	-
	Local	-	5.5 mg/kg	-	-	-
	Parking lot	-	5.5 mg/kg	-	-	-
Chlorides	-	5 mg/kg	0-4,500 mg/kg	175-2,250 mg/kg	-	971 mg/l
Oils	All sites	-	28.6 mg/kg (mean	28.6 mg/kg (mean)	-	-
Greases	All sites	-	19.6 mg/kg (mean)	19.6 mg/kg (mean)	-	-
Phosphates	-	-		1.5 mg/kg (mean)	-	-
	Arterial streets	-	0.032 mg/kg (mean)	-		-
	Collectors	-	0.087 mg/kg (mean)	-	-	-
	Local	-	0.065 mg/kg (mean)	-		-
Lead		0.002-0.25 mg/kg		0.9-9.5 mg/kg	0.048-0.173 mg/l	0.143 mg/l(mean)
	Residential	-	2 mg/kg (mean)	-	-	-
	Industrial	-	4.7 mg/kg (mean)	-	-	-
	Commercial	-	3.7 mg/kg (mean)	-	-	-
	Highway	-	102.0 mg/kg	-	-	-
Cadmium	-	-	-	<0.05 mg/kg	-	-
Barium	-	-	-	<0.50 mg/kg	-	-
Zinc	-	-	-	0.60 mg/kg	-	-
Copper	-	-	-	0.19 mg/kg	-	-
Iron	-	-	-	30.0 mg/kg	-	-
Chromium	-	-	-	<0.02 mg/kg	-	-
Arsenic	-	-	-	<0.02 mg/kg	-	-

Source: "Snow Disposal Study of the National Capital Area: Technical Discussion", J.L. Richards and Associates, Ltd., and Labreque, Vezina and Associates, for the Committee on Snow Disposal, Ottawa, Ontario, June, 1973.

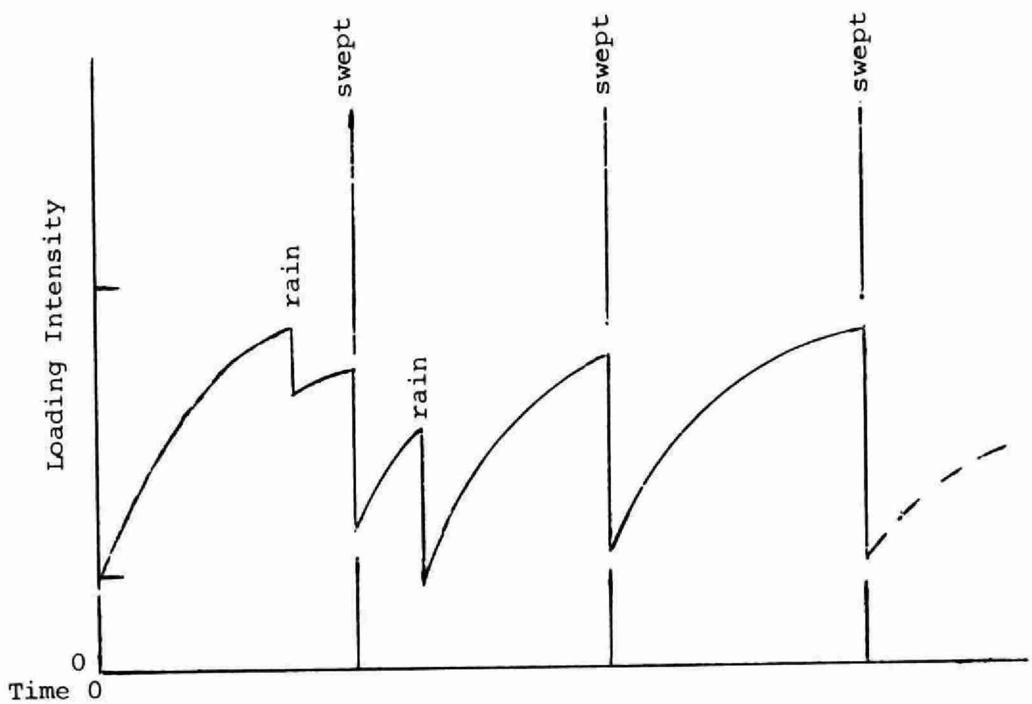

FIGURE 1. ACCUMULATION OF CONTAMINANTS - TYPICAL CASE (Natural Buildup with Periodic Sweeping and Intermittent Rainfall)

and SWMM as presented in Table 5. In this table, the pollutant loading rates are seen to vary with land use - residential (single family and multi-family), commercial, industrial and open [6]. Data collected in the Brucewood Catchment of North York [7] (described in the Appendix) indicated an average accumulation rate in August 1975 of 0.69 lb of dust and dirt per day per 100 feet of gutter, with a range of 0.04 to 2.61 lb per day per 100 feet of gutter.

Analysis of data collected in the Malvern Catchment [8] (described in the Appendix) tends to support the concept of daily accumulation of pollutants with washoff by rainfall. From 83% to 92% of the linear variation in the runoff loadings of four parameters was explained by linear variation in the antecedent dry period. It was further shown that significant correlations existed between the loadings of the four parameters; however, it was considered desirable to consider the pollutant loadings individually. It was felt that the processes governing the various parameter loadings could differ significantly from parameter to parameter.

TABLE 5. PARAMETERS FOR SURFACE POLLUTANT ACCUMULATION USED IN SWMM AND/OR STORM

Except as noted, values are for soluble portion and derived from 1969 APWA Chicago study.

Parameter	Units	Land Use				
		Single-family res.	Multi-family res.	Commercial	Industrial	Open[a]
Dust and dirt loading, dd_L	lb/day-curb-mile	40.0	121.0	174.0	243.0	79.2
	kg/day-curb-km	11.4	34.4	49.4	69.0	22.5
Pollutant fractions[b], $F_{P,L}$:						
SS[a] (SWMM)		1.0	1.0	1.0	1.0	1.0
SS[a] (STORM)		0.111	0.08	0.17	0.067	0.011
Settleable Solids[c] (SWMM)		0.1	0.1	0.1	0.1	0.1
Settleable Solids[c] (STORM)		0.011	0.008	0.017	0.007	0.111
BOD_5		0.005	0.0036	0.0077	0.003	0.005
COD		0.04	0.04	0.039	0.04	0.02
Total PO_4		0.00005	0.00005	0.00007	0.00003	0.00001
Total N		0.00048	0.00061	0.00041	0.00043	0.00005
Grease[a]		0.001	0.001	0.001	0.001	0.001
Total Coliforms	MPN/g	1.3×10^6	2.7×10^6	1.7×10^6	1.0×10^5	0.00

[a]All values assumed

[b]Fraction refers only to soluble fraction of dust and dirt (except for solids).

[c]All values assumed at 10% of value for SS.

When pollutants are washed off road surfaces, a certain proportion of the settleable solids is retained in the catch basin sumps common in storm sewer systems. The materials decompose in the catch basin sump, often increasing the bacterial populations and other parameters. It was recommended in one study [9] in East York that catch basin sumps serve little useful purpose in the well developed, older sections of the Borough, and that their removal would improve the quality of runoff in the early stages of runoff events. The high concentrations of pollutants in the sumps was thought to partially explain the occurrence of a "first flush" in the runoff data. Table 6 presents measured constituent concentrations from catch basins in North York [7].

POLLUTANT CHARACTERIZATION

Pollutants in urban runoff can be characterized by oxygen demand, solids fractions, nutrients, bacteria, heavy metals, pesticides, grease and oil, and de-icing salts. Oxygen-demanding substances (measured by the biochemical oxygen demand-BOD test) generally consist of organic material which is decomposed by bacteria using up oxygen in the process. BOD oxidation affects receiving waters by reducing oxygen in some cases to levels below those required for fish survival.

Solids can be considered as either suspended or soluble. A portion of the suspended solids can be considered settleable. Suspended solids in urban runoff and from erosion can act as a pollutant directly: by increasing the turbidity of water, causing reduced light penetration, aesthetic nuisance, and reduced algal production; by settling in gravel beds, thus destroying fish habitat; by clogging and clouding fish gills; and by destroying the habitat of bottom dwelling organisms. Other pollutants are often associated with solids. The degree of association with settleable solids of various contaminants affects the ability of the contaminant to be removed by sedimentation methods, either naturally in the environment or with a treatment technique.

The primary algal nutrients of concern are nitrogen and phosphorus compounds. Nutrients in runoff contribute to the overproduction of algae and plants in rivers and lakes, leading to the condition of eutrophication.

TABLE 6. CATCH BASIN SUMP WATER QUALITY

LOCATION	BOD mg/l	COD mg/l	Susp. Solids mg/l	Phosphorus Tot. mg/l	Phosphorus Sol. mg/l	Cl mg/l	Pb mg/l	Total Kjeld. mg/l	Nit-rate mg/l	Ammo-nia mg/l	Phen-ols mg/l	Coliform Total (MPN/100 ml)	Coliform Fecal (MPN/100 ml)
BRUCEFARM DR. *													
Arithmetic Mean	91.8	880	6378	7.7	0.67	329	5.3	35.6	-	2.0	41	79333	4566
Range	30-190	190-2100	1300-15970	2-17	0.04-2.9	18-3150	2.5-10	15-70	<0.2-0.4	0.4-3.6	2-110	-	-
# of Samples	10	10	11	10	11	11	9	10	10	11	9	1	1
CUMMER AVE. *													
Arithmetic Mean	87.8	1059	5577	5.6	0.16	3795	26.3	29.9	-	2.1	40	2000	133
Range	20-260	250-4100	1000-187000	1.6-10	<0.02-0.80	31-21700	9-120	8-60	<0.2-<0.4	0.1-12.0	7-100	-	-
# of Samples	9	9	10	8	10	10	9	8	10	10	8	1	1

* Reference: James F. Maclaren, "Report on the Brucewood Monitoring Program" (Draft), COA Project 73-3-12, 1975.

Bacteria and viruses in runoff represent a health hazard to man and to aquatic organisms. Heavy metals such as lead, copper, zinc, chromium, mercury and nickel can cause toxic conditions for aquatic life and also tend to be concentrated in the food chain to the point where fish may become unsuitable for eating. Pesticides can be persistent or non-persistent in the environment. These also lead to toxicity problems and concentration in the food chain. Greases and oils can be toxic and also are unsightly on water surfaces. De-icing salts can lead to stratification problems in lakes, to taste problems in water supplies, and to hypertension problems for people on low sodium diets.

URBAN RUNOFF QUALITY IN ONTARIO

Documentation of urban drainage quality requires complex instrumentation for sampling runoff events. Proper evaluation of the effects of runoff requires flow estimates in parallel with samples, an understanding of the characteristics of the catchment and records of rainfall and snowmelt [16]. The Appendix describes urban runoff research catchments in Ontario which are well instrumented and the characteristics of which are well known. This includes 11 storm drainage catchments, two combined sewer flow catchments and four sanitary flow bypass locations. The characteristics of the 17 catchments are summarized in Table 7. Table 8 summarizes the quality parameters - range of concentration and range of mean concentrations for each catchment. More extensive information related to characteristics of the catchments and the monitored water quality parameters is included in the Appendix and the supporting referenced reports.

Generally, on a storm event basis, the data indicate that most of the parameters tend to increase with the length of the antecedent dry weather period, becoming less sensitive after approximately 10 days. Some parameters indicated sensitivity to the age of the catchment; for example, BOD concentrations appear to be lower for relatively new urban areas, while suspended solids are higher. Some catchments tend to indicate some irregularities; for example, the London-Carlington catchment, where apparently the "fugitive" pollutant inflow seems to be the overriding factor. The study of the baseflow in the above-mentioned

TABLE 7. URBAN DRAINAGE CATCHMENT SUMMARY

SUMMARY \ CATCHMENT NAME & LOCATION	North York Brucewood	East York Barrington	East York Broadview	Burlington Malvern	Burlington Aldershot	Guelph North	Guelph West	Windsor "A"
Catchment Number	1	2	3	4	5	6	7	8
Drainage Area (hectares)	19.44	22.7	25.3	23.1	6.9	58.8	221.9	12
Imperviousness - gross (%)	48.3	--	--	34	100	39.0	36.8	--
- directly connected (%)	38.6	--	--	31	100	35.7	19.9**	--
Land Use - Open (%)	--	--	--	--	--	7.3	24	--
- Residential (%)	100	100*	100*	100	--	86.9	59	100*
- Commercial-Inst. (%)	--	--	--	--	100	5.8	--	--
- Industrial (%)	--	--	--	--	--	--	17	--
Population Density (cap/ha)	36	--	--	43.3	--	--	--	50
Age (period)	1960	1910-1930	1920	1960		1960	1930-1960	1945-1960
Direct Connection of Roof Runoff	Yes	No	No	Yes	Yes	Yes	Partial	
Street Sweeping Frequency								
- main streets	weekly	--	--	biweekly	--	weekly	weekly	--
- local streets	biweekly	--	--	biweekly	--	monthly	monthly	--
Monitoring Period	Apr/74 - Dec/75	May/74 - Feb/76	Sep/73 - Nov/74	1973 - Dec/75	Jul/75 - Aug/75	Jul/75 - Jun/76	Jul/75 - Nov/76	Sep/72 - Aug/73
- precipitation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
- flow quantity	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
- quality	Yes	Yes	Tes	Yes	Yes	Yes	Yes	Yes
Reference No.	7	9	9	8,20	16,17	18	21	19

* indicates predominantly residential
** some impervious surface connected throughout ditch drainage

TABLE 7. (CONT'D)

CATCHMENT NAME & LOCATION / SUMMARY	Windsor "B"	London Carling St.	Kitchener Schneider's (Montgomery Creek)	East York Frankdale Combined	Hamilton Combined	Aurora Bypass Combined	Brantford Bypass Sanitary	Waterloo Bypass Sanitary
Catchment Number	9	10	11	12	13	14	15	17
Drainage Area (hectares)	36	45	3580	155	71	4850	4650	6632
Imperviousness - gross (%)	--	65	--	49	36	--	--	--
- directly connected (%)	--	--	--	--	--	--	--	--
Land Use - Open (%)	--	24	50	4.2	20	--	31	57
- Residential (%)	100*	14	42	90.1	75	--	43.5	27
- Commercial-Inst. (%)	--	33	4.8	5.7	5	--	7	6
- Industrial (%)	--	27	4.3	--	--	--	18	10
Population Density (cap/ha)	25	62.2	2.7	94	43	2.8	18.4	16.5
Age (period)		1916			Prior 1950			
Direct Connection of Roof Runoff			Partial	Yes	Yes	Partial		Yes
Street Sweeping Frequency								
- main streets	--	Every 2 days	--	--	weekly	--	--	--
- local streets	--	Every 2 wks	--	weekly	monthly	--	--	--
Monitoring Period	Unknown	Sep/76 - Nov/76	Jan/76 - Apr/76	Jan/76 Jul/76	Oct/75 - Sep/76	Feb/74 - Nov/74	Jan/74 - Nov/75	Feb/74 - Nov/74
- precipitation	Yes		--	Yes	Yes			
- flow quantity	Yes	Yes	--	Yes	Yes	Yes	Yes	Yes
- quality	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reference No.	11	12,13	15	22	23	14	14	14

* indicates predominantly residential
** some impervious surface connected throughout ditch drainage

TABLE 8. DRAINAGE QUALITY DATA SUMMARY

CATCHMENT \ PARAMETERS		BOD$_5$ mg/l	COD mg/l	SOLIDS total mg/l	SOLIDS susp mg/l	Cl mg/l	Pb mg/l	NITROGEN Kjel. mg/l	NITROGEN NO_2^- mg/l	NITROGEN NO_3^- mg/l	PHOSPHORUS total mg/l	PHOSPHORUS susp. mg/l	PHENOLS ppb	COLIFORMS total MPN/100 ml	COLIFORMS fecal MPN/100 ml
1. BRUCEWOOD range of concentration	min.	0.2	<10	300	10	2	0.02	0.3	<0.02	<0.2	0.04	<0.02	0	1.0×10^2	1.0×10^1
	max.	110	920	1200	1000	10,300	1.80	19.0	0.26	4.7	1.60	0.68	43	1.1×10^5	1.9×10^4
range of means *	min.	9.3	66.0	-	81	354	0.32	2.2	-	1.4	0.22	0.06	4.3	-	-
	max.	18.0	125.5	-	149	976	0.54	4.0	-	2.3	0.43	0.11	12	-	-
2. BARRINGTON range of concentrations	min.	-	-	-	-	-	-	-	-	-	-	-	-	1.0×10^4	1.0×10^3
	max.	320	880	-	630	7075	1.80	20.0	0.90	2.1	11.0	-	145	4.7×10^6	1.1×10^6
range of means **	min.	4.6	30.1	-	41.6	4.5	0.18	0.8	0.020	0.4	0.20	-	1.1	-	-
	max.	188.1	700.3	-	314.7	5855.1	1.40	10.9	0.393	1.3	2.88	-	108.9	-	-
3. BROADVIEW range of concentrations	min.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	max.	48	490	-	400	84	0.46	7.5	0.14	2.1	1.00	-	7	-	-
range of means **	min.	9.9	72.8	-	50.8	19.8	0.32	1.3	0.085	-	0.28	-	1.6	-	-
	max.	23.0	195.9	-	232.4	71.0	0.85	3.6	0.090	-	0.58	-	5.7	-	-
4. MALVERN range of concentrations	min.	-	5.3	-	2.8	-	-	-	-	-	0.01	-	-	-	-
	max.	-	312	-	681	-	-	-	-	-	1.50	-	-	-	-
range of means **	min.	-	22.0	-	6.8	-	-	-	-	-	0.01	-	-	-	-
	max.	-	119.6	-	194.8	-	-	-	-	-	0.51	-	-	-	-
5. ALDERSHOT range of concentrations	min.	-	12.4	-	4.0	-	<0.05	-	-	-	0.05	-	-	-	-
	max.	-	490	-	380	-	1.30	-	-	-	5.40	-	-	-	-

* arithmetic mean of concentrations for runoff event
** flow weighted mean of concentrations for runoff event

TABLE 8. DRAINAGE QUALITY DATA SUMMARY (CONT'D)

PARAMETERS / CATCHMENT		BOD_5 mg/l	COD mg/l	SOLIDS total mg/l	SOLIDS susp mg/l	Cl mg/l	Pb mg/l	NITROGEN Kjel. mg/l	NITROGEN NO_2^- mg/l	NITROGEN NO_3^- mg/l	PHOSPHORUS total mg/l	PHOSPHORUS susp. mg/l	PHE-NOLS ppb	COLIFORMS total MPN/100 ml	COLIFORMS fecal MPN/100 ml
6. GUELPH-NORTH range of concentration	min.	0.20	18	72	10	1	-	0.4	0.01	<0.2	0.04	0.004	-	$<1.0 \times 10^4$	$<1.0 \times 10^3$
	max.	60	320	2300	1090	68	-	5.3	0.22	4.6	1.6	0.072	-	8.3×10^5	7.1×10^4
range of means **	min.	7.8	60	364	87	22	-	2	0.06	0.59	0.25	0.020	-	-	-
	max.	17.7	89	564	159	67	-	3	0.10	1.05	0.35	0.028	-	-	-
7. GUELPH-WEST range of concentrations	min.	0.6	20	153	5	7.8	-	0.2	0.007	0.01	0.04	0.002	-	6.0×10^4	5.5×10^4
	max.	90	200	780	352	103	-	15	1.80	1.70	1.10	0.060	-	1.4×10^7	5.7×10^5
range of means **	min.	2.3	43	136	55	3	-	0.9	0.02	0.36	0.013	0.015	-	-	-
	max.	14.9	168	1335	301	58	-	2.0	0.12	3.65	0.22	0.040	-	-	-
8. WINDSOR 'A' range of concentrations	min.	0	-	-	23	4	-	-	0.001	0	-	-	-	2.0×10^2	1.0×10^2
	max.	78.4	-	-	1230	1585	-	-	0.570	4.7	-	-	-	1.2×10^6	2.0×10^6
range of means **	min.	14.0	-	-	111	29	-	-	0.045	1.05	-	-	-	-	-
	max.	26.8	-	-	467	122	-	-	0.024	1.37	-	-	-	-	-
9. WINDSOR 'B' range of concentrations	min.	2	-	-	2	4	-	-	0.01	0.05	-	-	-	1.4×10^3	-
	max.	52	-	-	4122	2580	-	-	0.[illegible]3	6.30	-	-	-	1.8×10^7	2.3×10^5
range of means **	min.	8	-	-	86	27	-	-	0.04	0.81	-	-	-	-	-
	max.	16	-	-	741	345	-	-	0.16	2.64	-	-	-	-	-
10. CARLING ST. range of concentrations	min.	5.6	21	-	6	-	-	-	-	-	0.05	<0.05	28	1.0×10^5	6×10^2
	max.	630	1096	-	209	-	-	-	-	-	20	7.45	64	2.2×10^6	7.9×10^2
range of means **	min.	16.8	-	-	37	-	-	-	-	-	0.61	-	-	-	-
	max.	42.5	-	-	39	-	-	-	-	-	0.76	-	-	-	-

* arithmetic mean of concentrations
** flow weighted mean of concentrations

TABLE 8. DRAINAGE QUALITY DATA SUMMARY (CONT'D)

PARAMETER / CATCHMENT		BOD5 mg/l	COD mg/l	SOLIDS total mg/l	SOLIDS susp mg/l	Cl mg/l	Pb mg/l	NITROGEN Kjel. mg/l	NITROGEN NO_2^- mg/l	NITROGEN NO_3^- mg/l	PHOSPHORUS total mg/l	PHOSPHORUS susp mg/l	PHE-NOLS ppb	COLIFORMS total MPN/100 ml	COLIFORMS fecal MPN/100 ml
11. SCHNEIDER'S CREEK															
range of	min.	-	-	-	5	-	0.003	0.36	-	-	0.028	-	-	-	-
concentrations	max.	-	-	-	890	-	0.92	2.52	-	-	0.730	-	-	-	-
12. FRANKDALE															
range of	min.	4	35	79	6	6	0.01	1.8	0.01	0.01	0.20	0.02	1	-	-
concentrations	max.	280	1090	20470	2115	3064	4.80	26	0.70	2.8	6.20	1.70	60	-	-
13. HAMILTON															
range of	min.	7.7	25	-	25	-	-	-	-	-	0.8	-	-	-	-
concentrations	max.	200	2000	-	2745	-	-	-	-	-	28	-	-	-	-
14. AURORA															
range of	min.	11	-	-	79	258	-	17	-	-	2.1	-	-	-	-
concentrations	max.	237	-	-	546	487	-	40	-	-	7.1	-	-	-	-
15. BRANTFORD															
range of	min.	46	-	-	161	-	-	12	-	-	3.4	-	-	-	-
concentrations	max.	303	-	-	857	112	-	24	-	-	7.6	-	-	-	-

catchment and the Aldershot catchment show high concentrations of pollutant parameters such as BOD, bacteriological counts, etc. The Aldershot (commercial) catchment was compared to the Malvern (residential) catchment for two identical storms as shown in Table 9, indicating relative magnitudes of five parameters, COD, Cl, P and Pb are significantly higher in the commercial catchment, while nitrogen (nitrite plus nitrate) is higher in the residential catchment.

Seasonal variation is also recognized in the data. The spring periods produced the highest concentrations of most parameters with the exception of chlorides, which were highest in winter.

Special microbiological studies were carried out at several storm sewer locations - Aldershot, Malvern, and Brucewood [17] and Guelph and East York [32]. The levels of microbial populations in storm runoff were strikingly high throughout the entire sampling period. Many times these levels approached densities found in raw sewage and therefore constitute a health hazard. This is particularly due to the presence of disease-causing bacteria.

These studies conclude that storm water can be a major source of pollution to receiving waters used for recreational purposes. In order to prevent public health risks and deterioration of surface water quality in general, the reports concluded that it is imperative that control measures and treatment methods be developed to handle large volumes of discharge from separate storm sewer systems.

URBAN RUNOFF POLLUTANT LOADS

The level of detail required in the characterization of storm water loads is dependent on the time and space scales of the potential receiving water effects (discussed subsequently). Storm water may be considered on the basis of annual loads, event loads, or loading rates within events, as illustrated in Figure 2.

The American Public Works Association, with the University of Florida, evaluated the magnitude of storm water loads from combined, separated and unsewered areas in Ontario and compared these to dry weather loads [6]. The estimate was based on population, land use and sewer system information for 56 cities in Ontario which drain to the Great Lakes

TABLE 9. COMPARISON OF STORM WATER RUNOFF QUALITY BETWEEN MALVERN AND ALDERSHOT CATCHMENTS

STORM EVENT	MALVERN (Residential)					ALDERSHOT (Commercial)					RATIO OF MALVERN TO ALDERSHOT CONCENTRATIONS				
	N mg/l	COD mg/l	P mg/l	SS mg/l	Pb mg/l	N mg/l	COD mg/l	P mg/l	SS mg/l	Pb mg/l	N	COD	P	SS	Pb
July 19/75 Mean Conc.	1.90	56.5	0.20	43	0.12	0.47	137.1	1.82	81	0.41	4.0	0.4	0.1	0.5	0.3
No. of Samples	16	16	16	16	16	14	14	14	14	14					
August 21/75 Mean Conc.	1.29	38.6	0.21	32	<0.05	0.26	112.9	0.34	157	0.50	5.0	0.3	0.6	0.2	<0.1
No. of Samples	14	14	14	14	13	13	13	13	13	13					

N is given as nitrate plus nitrite nitrogen

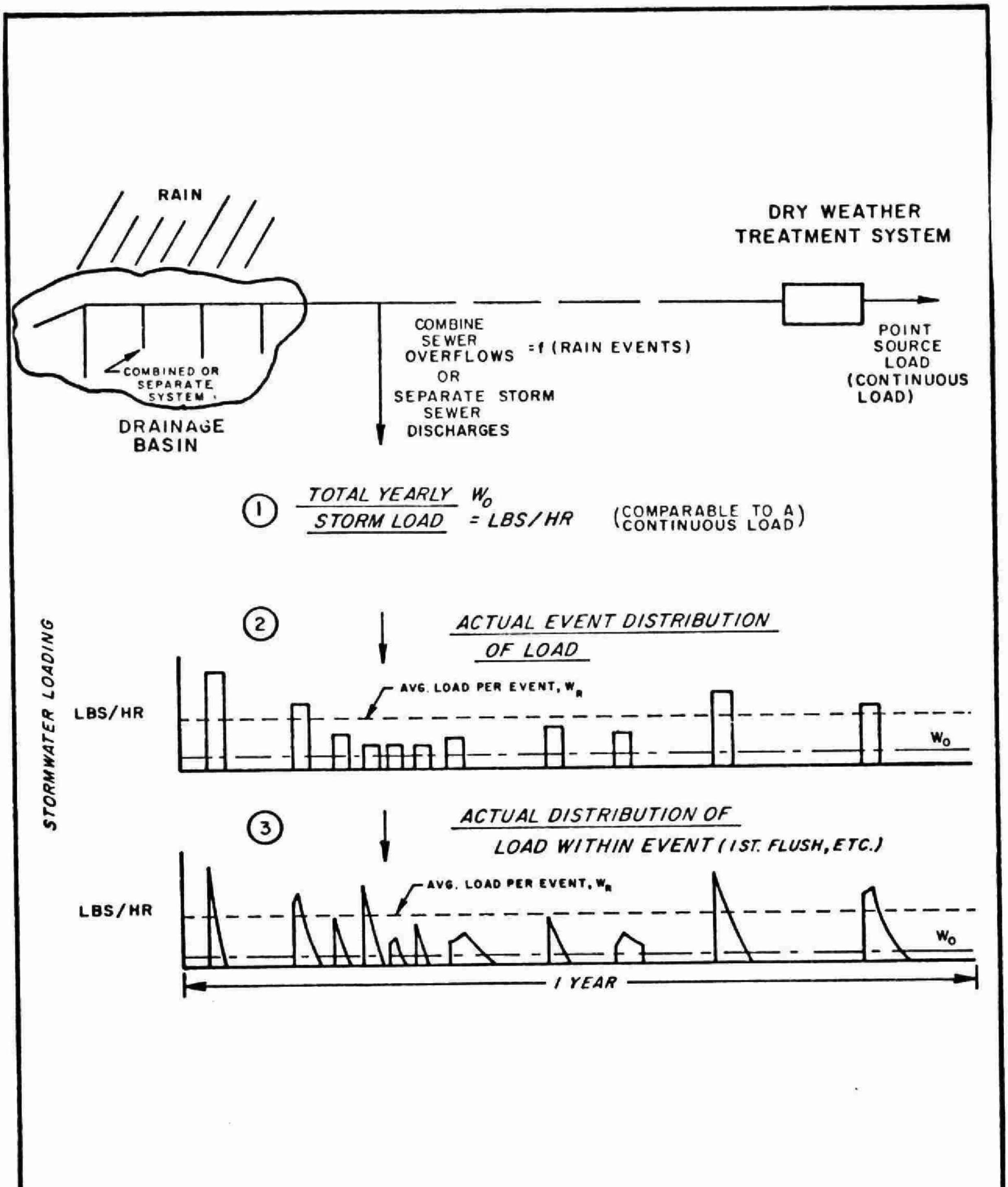

FIGURE 2
VARIOUS LEVELS OF DETAIL IN
STORMWATER LOAD CHARACTERIZATION
(REFERENCE 35)

as summarized in Table 10. Table 11 presents population statistics and wet weather pollution loads from urban areas for BOD, nitrogen and phosphates. Table 12 gives a summary indicating the relative population, land areas and pollutant loads for each type of sewerage system. It is interesting to note that combined sewerage areas contribute approximately 53% of the pollutant load while occupying only 18% of the developed urban area. This is because combined sewered areas typically are inner city areas with high population densities, and high percentage imperviousness; as well as the fact that sanitary flows contribute to the overflow load.

The total BOD load from urban runoff of 7.7 million kg (17 million pounds) per year is comparable to the total load from dry weather treatment plants of approximately 12 million kg (26 million pounds) per year (assuming secondary treatment for all urban areas served by sanitary sewers, and a per capita BOD load of 0.077 kg). Assuming urban runoff occurs 6% of the time in a year, urban runoff loads are ten times larger than that discharged by treatment plants in the wet weather period vs. 65% as large on an annual basis.

These estimates are based on simple assumptions and thus are only approximations. The actual load from each city would vary greatly from these approximations, although in the aggregate the estimates are thought to be reasonable.

RECEIVING WATER EFFECTS

The problems which occur in receiving waters depend on the characteristics of the receiver, the uses made of the receiver, the time scale of the problem, and the characteristics of the discharge.

The characteristics of the receiver lake or river govern the ability of the water system to dilute, transport, settle, disperse, decay or otherwise assimilate the contaminating material. The uses made of the receiver determine the contaminating parameters which are most likely to affect the receiving stream. These parameters include the constituents in runoff, the mass of the constituent, the duration and frequency of discharge events. Figures 3 and 4 illustrate the time and space scales associated with the impact that contaminants discharged in storm water have on receiving waters. The possible long and short term effects of runoff pollution on lakes and rivers are summarized below.

TABLE 10. URBAN CHARACTERISTICS OF 56 CITIES IN ONTARIO GREAT LAKES AREA

Total Urban Area *	585,880 acres; 237,100 ha
" Urban Population	4,725,300 people
" Average Population Density	8.07 persons/acre; 19.9 p/ha
" Average Precipitation	32.8 inches; 83.3 cm

	Land Use and Sewer System	
	% of Total Area	% of Developed Area
Land Use		
Undeveloped	32.6	
Residential	34.9	51.7
Commercial	6.3	9.3
Industrial	9.3	13.8
Other **	16.9	25.0
Total	100.0	100.0
Sewer System		
Undeveloped	32.6	
Combined sewers	12.2	18.0
Storm sewers	35.8	53.0
Unsewered ***	19.5	29.0
Total	100.0	100.0

* 56 Cities draining into the Great Lakes, with 1971 populations greater than 10,000.

** Recreational, schools and cemeteries; open space.

*** No sanitary sewers, served by septic tanks.

Reference: [31].

TABLE 11. POPULATION STATISTICS AND POLLUTANT LOAD BY TYPE OF SEWER SYSTEM

	Combined	Storm	Unsewered	Total	Average (weighted)
Population Served x 10^3	1773	2485	468	4725	-
Population Density in developed area, per/ac. (P/ha)	24.9 (69.5)	11.9 (29.4)	4.1 (10.1)	-	12.0 (29.7)
Runoff inches of precipitation (cm)	17.1 (43.4)	13.0 (33.0)	9.5 (24.1)	-	13.0 (33.0)
Wet weather BOD load lb/acre/year (kg/ha/yr)	133.2 (149.4)	27.4 (30.7)	23.3 (26.1)	-	45.3 (50.8)
lb/acre/year (kg/ha/yr)	9520 (4322)	5750 (2610)	2660 (1207)	17,930 (8,140)	-
Wet Weather Phosphate (PO_4) Load lb/acre/year (kg/ha/yr)	5.3 (5.91)	1.1 (1.2)	0.9 (1.0)	-	1.8 (2.0)
1000 lb/year (kg/yr)	380 (172)	230 (104)	100 (45.4)	710 (322)	-
Wet Weather Total Nitrogen Load lb/acre/year (kg/ha/yr)	20.8 (23.3)	4.2 (4.7)	3.5 (3.9)	- -	7.0 (7.8)
1000 lb/year (kg/yr)	1490 (677)	880 (400)	400 (182)	2770 (1260)	-

TABLE 12. PERCENT POPULATION, AND AREA AND POLLUTANT LOAD BY TYPE OF SEWER SYSTEM

Type of Sewer System	Percent Population	% Dev. Area	% BOD Load	% N Load	% PO_4 Load
Combined	37.5	18	53	53	53
Storm	52.5	53	32	32	32
Unsewered	10.0	29	15	15	15

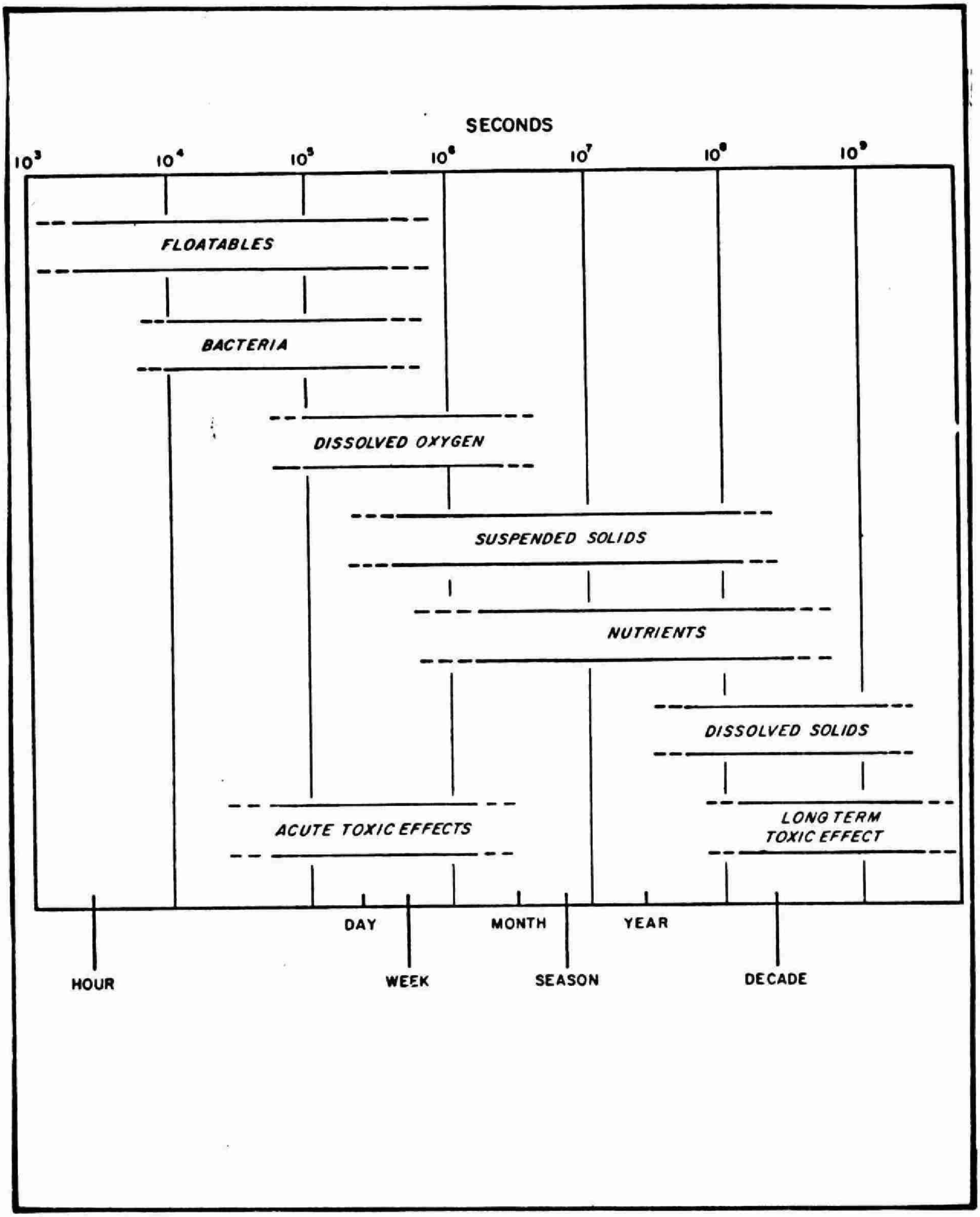

FIGURE 3
TIME SCALES
STORM RUNOFF WATER QUALITY PROBLEMS
(REFERENCE 35)

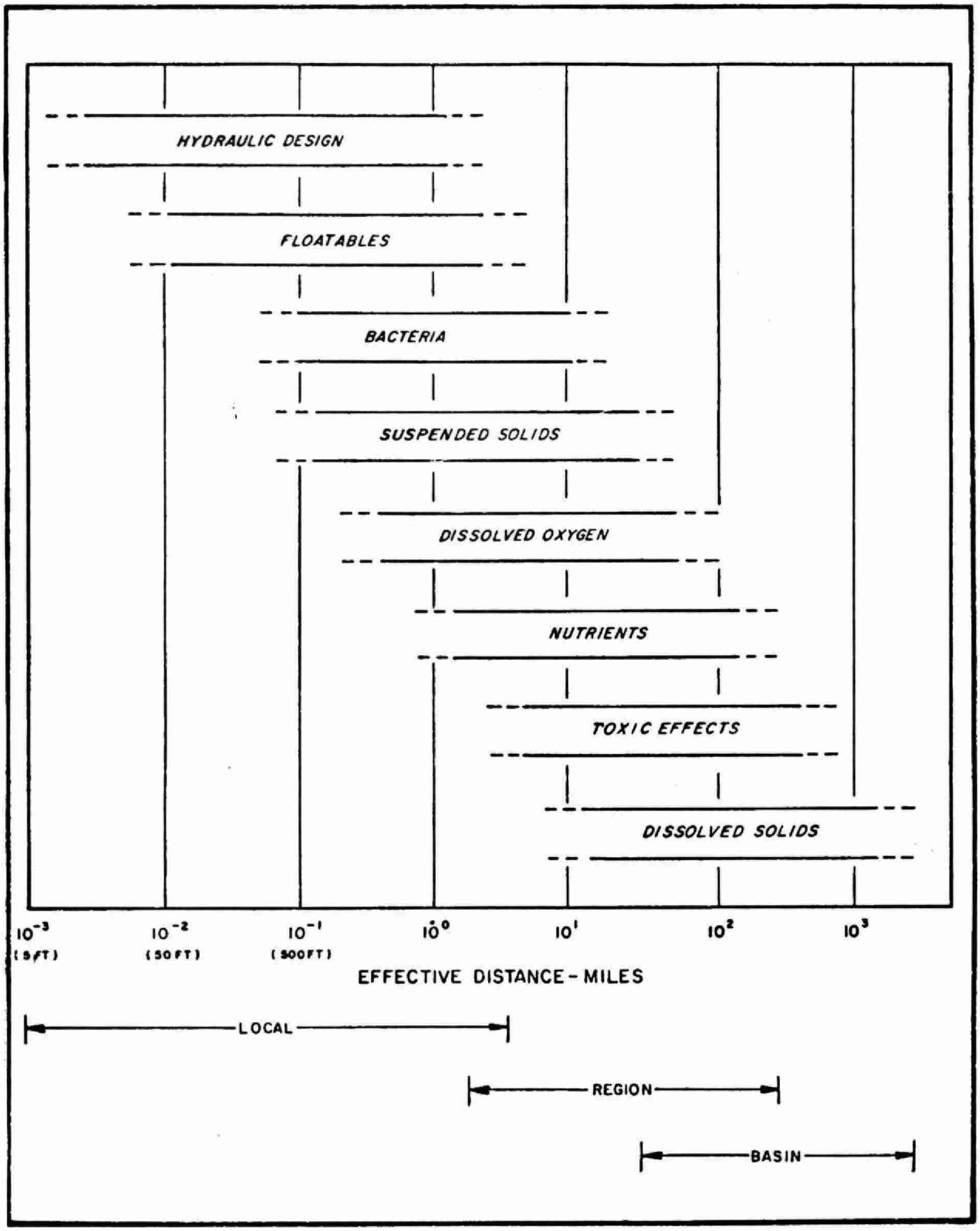

FIGURE 4
SPACE SCALES
STORM RUNOFF WATER QUALITY PROBLEMS
(REFERENCE 35)

a) Long term effects on lakes:
- gradual build up of nutrients in water and sediment,
- gradual build up of heavy metals and pesticides on sediments and in the food chain,
- salt build up,
- sediment build up at the mouth of rivers and at outfalls.

b) Long term effects on rivers:
- destruction of habitat for fish and aquatic biota by sediments,
- elevated nutrient, heavy metals and pesticides concentrations through decomposition and desorption from sediments,
- reduced oxygen levels by decomposition of sediments,
- physical changes resulting from changes in natural hydrology also affect receiving stream quality.

c) Short term effects on lakes:
- pollution of bathing beaches and water intakes following runoff events,
- aesthetic pollution from turbidity and litter,
- stress on aquatic life during and immediately following runoff events from toxic materials and oxygen demand exertion.

d) Short terms effects on rivers:
- same as for lakes (above).

EXAMPLES OF RECEIVING WATER PROBLEMS

Numerous cases exist where urban runoff is cited as a suspected cause of observed pollution problems. These conclusions are often based on inference due to the difficulty in establishing direct relationships between runoff and receiving water effects. In view of the evidence presented previously, indicating the presence of contaminants in urban runoff and the magnitude of urban runoff loads, it is considered that the inference of problems from urban runoff is correct.

Recent findings by the Ontario Ministry of the Environment and others have led to recommendations for control of existing problems and prevention of future problems from urban runoff. Several examples are discussed in the Urban Drainage Manual of Practice [24] and mentioned briefly here.

In the Thames River Basin Study [25] urban runoff was recognized as a source of pollution and recommendations were made to control this source.

In the Lake Simcoe Study [26] storm water management for future development was recommended to protect the lake from further degradation. In the Kettle Creek report [27], controls on combined overflows and treatment plant bypasses were recommended for the City of St. Thomas, to alleviate severe degradation of the creek downstream from the city.

In the Rideau River [28], bacteriological pollution of bathing beaches from urban runoff has been cited as a justification for requiring new urban developments to install storm water quality controls prior to discharge.

In the Midland Lake watershed [29], it was predicted that proposed urban development would cause the lake to become unsuitable for swimming and for fish unless specific measures such as storm water treatment were undertaken.

In a study on the Toronto Waterfront area [30] storm and combined sewer discharges were cited as contributors to short term problems following runoff events and to long-term problems in the harbour. Recommendations were made to continue with combined sewer overflow control programs and to further quantify the magnitude duration and frequency of overflow and storm sewer loads.

CONCLUSIONS

It can be concluded that:

1. Urban runoff contains contaminants which have a potential for degrading water quality, impairing water uses, and which threaten aquatic life and represent a health hazard for man.
2. Estimates for urban runoff loads, including combined sewer overflows, indicate that the magnitude is of the same order as treated wastewater loads, on an annual basis, and is an order of magnitude larger on the average, during runoff events.
3. Evidence indicates that urban runoff is causing receiving water problems and impairing water uses.

4. Continued uncontrolled overflows of combined sewers and storm water would have the effect of further degrading water quality. New urban developments under present practices would add to the degradation.
5. The significance of urban runoff pollution loads, compared to other sources, on Great Lakes water quality will be established as part of future work by the Great Lakes Water Quality Board, Pollution from Land Use Activities Reference Group.

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APPENDIX

This Appendix presents a description of drainage catchments and a summary of quality data for urban runoff from 17 catchments in Ontario. The catchments are categorized as 11 storm water, 2 combined sewage sites, and 4 sanitary and combined sewer bypasses. Catchments in Ontario are exclusively outlined here since this is the prime area of interest for the Urban Drainage Subcommittee activities [34]. Other catchments in Canada and elsewhere are available but were not included in this review since they are adequately described in "Urban Hydrological Modelling and Catchment Research in Canada" by J. Marsalek [16].

1. Brucewood Catchment [7]

The Brucewood catchment is located in the north-east corner of the Borough of North York in Metropolitan Toronto, about 15 miles from the centre of the city. Drainage in the catchment is from east to west along Cummer Avenue from Leslie Street in the east to the west branch of the Don River in the west. The drainage boundaries are the East Don River Valley on the north, west and south sides, and the CNR tracks on the east side, defining an area of 19.52 hectares (48.23 acres). The elevation ranges from about 153 metres (500 feet) to 157 metres (516 feet) above sea level and the surface slopes are moderate, in the order of 3%.

The catchment is served by a separate storm sewer system, connected to roof leaders and road catch basins and draining through a 99 cm (39 in) dia. outfall into the East Don River.

The land use in the catchment is modern residential, characterized by large, single family detached and semi-detached residences built in the late 1960's. There are 169 detached units and 43 semi-detached. The catchment total gross imperviousness is 48.3%, with streets accounting for 2.84 hectares (7.0 acres), driveways 1.87 hectares (4.61 acres) and roofs (directly connected to storm sewer) 4.73 hectares (11.69 acres).

Street sweeping is conducted on a regular basis by the Borough of North York during the period between the spring clean-up in April-May until operations cease for the winter season in October. Cummer Avenue and Pineway Boulevard are swept once a week while all other streets once

TABLE A-1. BRUCEWOOD CATCHMENT [7]

AVERAGE CONCENTRATIONS OF RECORDED POLLUTANTS IN STORM RUNOFF MAY 1 to DECEMBER 31, 1974

DATE	AVG. FLOW RATE (cfs)	BOD_5 mg/l	COD mg/l	SOLIDS mg/l		P mg/l		Cl mg/l	Pb mg/l	TOTAL KJELDAHL mg/l	NIT-RATE mg/l	AMMO-NIA mg/l	PHEN-OLS ppb	COLIFORM (MPN/100 ml)	
				TOTAL	SUSP.	Tot.	Sol.							TOTAL	FECAL
4-29-74	-	-	105.7			0.61	.08	87.3	0.49	4.00	2.9	0.88	-	-	-
5-3-74	0.16	3.1	27.5	1023	30	0.05	.03	283.5	0.04	0.62	2.25	0.2	-	-	-
5-14-74	3.5	7.8	25	-	118	0.43	.06	61.0	-	11.5	0.83	0.13	-	-	-
5-16-74	1.26	4.8	30	809	71	0.02	<.02	151	0.13	1.22	1.9	0.26	-	2100	225
5-18-74	-	3.0	<20	-	15	0.15	.03	248	0.06	0.75	2.00	0.2	-	-	-
5-27-74	-	8.0	-	-	66	0.18	0.02	202	0.11	1.83	3.36	0.04	-	27600	2400
6-13-74	-	53.0	367.5	-	263	0.65	.02	132.5	1.06	4.9	2.42	1.58	-	-	-
11-3-74	-	11.7	52	-	18	0.1	<.02	53	0.06	1.5	1.7	.8	4	-	-
11-5-74	-	5.9	33	-	50	0.19	<.02	55	0.13	0.54	<.2	.2	<1	2680	1070
11-12-74	0.15	2.2	<20	-	<15	.05	<.02	7	.08	.5	<.2	.1	4	2220	520
11-20-74	3.9	12.9	52	-	281	0.38	.02	5	1.11	1.4	.4	<.1	7	6940	1500
11-24-74	-	4.7	36	-	30	.12	.02	65	.22	2.0	.8	.2	1	4948	1525
12-2-74	0.39	6.6	70	-	132	0.19	.02	681	0.76	1.2	<.2	<.1	9	4619	1700
12-15-74	-	4.2	-	49	-	.09	<.02	2050	<.05	.93	.8	.38	5.7	-	-
12-25-74	-	2.3	-	-	46	0.15	0.04	1225	0.18	1.00	.9	<.1	2.4	-	-

every two weeks. Catch basins are pumped out once a year in North York. During the winter, salt is applied to Cummer and Pineway while the back streets have a salt and sand mix (20 parts sand to 1 part salt) applied only infrequently during severe conditions. The application rate for salt is approximately 280 to 430 kg/km (1/2 to 3/4 ton/mi.). Since there is no parkland within the drainage boundaries and pesticides and herbicides are never used for weed control on sidewalks an curbs, there is no contribution to the runoff from this source.

Runoff quality samples were collected manually as well as automatically at intervals ranging from 5 to 15 minutes and analyzed for about 15 parameters. Samples of snowmelt water and snow slush were collected and analyzed. Additional quality data obtained included samples of catch basin contents, street dust and dirt and sewer baseflow, and are available in the MacLaren report. The Brucewood instrumentation system was fairly good, but plagued by frequent malfunctions and breakdowns.

Table A-1 shows the arithmetic mean concentrations of the constituents in the runoff for the storms monitored during the period from April to December, 1974. An inspection of Table A-1 reveals an apparent relationship between the season of the year and the concentration of some pollutants, namely nitrate nitrogen, orthophosphates (lawn fertilizers) and chlorides (de-icing salts).

Table A-2 indicates ranges of pollutant concentrations measured in storm water runoff for the periods April to December, 1974 and July to December, 1975.

Tables A-3 and A-4 indicate the ranges of observed pollutant concentrations and the arithmetic mean concentrations for each event, respectively, for the period from January 1 to May 15, 1975. The only significant difference in the quality of runoff during the snowmelt period is the apparent increase in concentration of chlorides and suspended solids resulting from the application of salt and sand to the roads for de-icing purposes.

2. East York-Barrington Catchment [9]

The Barrington catchment is located in the southeast corner of the Borough of East York in Metropolitan Toronto. Drainage in the

TABLE A-2. RANGE OF POLLUTANT CONCENTRATIONS (mg/l) MEASURED IN SURFACE RUNOFF IN BRUCEWOOD, NORTH YORK [7]

Pollutant	April/74 - Dec./74 Arithmetic Mean (mg/l)	April/74 - Dec./74 Observed Range (mg/l)	July/75 - Dec./75 Arithmetic Mean (mg/l)	July/75 - Dec./75 Observed Range (mg/l)	July/75 - Dec./75 No. of Samples
Solids					
Total	627	300-1200			
Suspended	81.1	<15- 770	120.0	<15-410	161
Dissolved	--	100-1170			
BOD_5	9.3	0.6-110	18.0	0.2-90	186
COD	69.9	<20-920	125.5	<10-315	156
Nitrogen					
Total Kjeldahl	2.26	0.3-19	2.20	0.4-5.7	188
Nitrate	1.39	0.2-4	2.27	<0.2-4.7	179
Nitrite	-	<0.02-0.26	-	-	-
Free Ammonia	0.35	0.1-3.3	0.54	<0.1-1.8	179
Phosphate					
Total	0.22	0.1-1.6	0.34	0.04-0.60	188
Soluble	-	-	0.06	<0.02-0.30	179
Sulphate	-	12-200	-	-	-
Chloride	353.8	2-3240	370.2	5-2631	182
Lead	0.32	0.2-1.8	0.42	0.02-1.60	118
Sodium	-	8-137	-	-	-
Potassium	-	1.3-15	-	-	-
Coliform (MPN/100 ml)					
Total	7301	100-82000	55417	2800-110000	27
Fecal	1277	10-7300	12150	930-19000	27
Entrococcus	-	20-4200	-	-	-
Phenols (ppb)	4.26	0-30	6.8	1-22	65

TABLE A-3. BRUCEWOOD CATCHMENT [7]

OBSERVED RANGE OF
POLLUTANT CONCENTRATIONS IN SNOWMELT
AND STORMWATER RUNOFF (mg/l)
January 1 - May 15/75

Pollutant	Observed Range mg/l	Average mg/l	No. of Samples
Suspended Solids	10-1000	149	127
BOD_5	1.4-55	11.4	124
COD	<20-160	66	74
Total Kjeldahl	.8-6	4	123
Nitrate	<.2-3.8	1.4	127
Ammonia	<.2-1.8	.4	127
Phosphorus - Total	.1-1.6	.43	124
- Soluble	<.02-.68	.11	127
Chloride	37 - 10,300	976	118
Lead	.02 - 1.1	.54	97
Phenols (ppb)	<1 - 43	12	127
Coliforms - Total	100- 13366	4457	4
- Fecal	100- 800	10	4

TABLE A-4. BRUCEWOOD CATCHMENT [7]

AVERAGE SAMPLE CONCENTRATIONS FOR EACH STORM (NOT CORRECTED FOR VOLUME OR DURATION) JANUARY 1 TO MAY 15, 1975

DATE	FLOW RATE (cfs)	BOD_5 mg/l	COD mg/l	SOLIDS mg/l TOTAL	SOLIDS mg/l SUSP.	P mg/l Tot.	P mg/l Sol.	Cl mg/l	Pb mg/l	TOTAL KJELDAHL mg/l	NIT-RATE mg/l	AMMO-NIA mg/l	PHEN-OLS ppb	COLIFORM (MPN/100 ml) TOTAL	COLIFORM (MPN/100 ml) FECAL
SNOWMELT ONLY															
Jan. 8/75	-	41	-	-	502	.95	.07	509	1.46	3.8	1.6	.30	7	-	-
Feb. 17	.23	10	-	-	88	.80	.34	350	.43	4.6	1.4	1.30	20	-	-
Feb. 22	-	6	66	-	107	.48	.23	163	.23	3.5	1.2	.68	15	-	-
Mar. 6	.01	9	-	-	90	.14	.03	-	.30	1.4	2.8	.25	15	4457	10
Mar. 12	.31	8	61	-	82	.31	.09	801	.34	8.4	1.6	.52	16	-	-
Mar. 19	-	8	-	1600	50	<.10	.10	668	.05	<0.1	1.4	.04	0	-	-
Mar. 21	-	6	-	2100	120	<.10	.02	1020	.13	<.1	1.2	.06	0	-	-
Mar. 25	-	5.5	-	3800	50	<.10	.01	2090	.11	<.1	1.1	.08	0	-	-
SNOWMELT + RAINFALL															
Jan. 3	-	12	-	-	232	.20	.02	5390	.57	2.3	1.1	.17	11	-	-
STORM RUNOFF ONLY															
Jan. 9	.33	2	-	-	38	.12	.02	252	-	.9	1.9	.1	1	-	-
Jan. 29	-	13	-	-	105	.34	.12	224	.28	.29	.2	.2	12	-	-
Feb. 24	5.50	3	49	-	337	.77	.23	55	.32	2.3	.22	.21	1	-	-
Mar. 19	.27	7	79	-	60	.39	.10	373	-	1.44	1.6	.17	9	-	-
May 4	.19	2.1	22	-	45	.11	.02	19	.14	.72	.4	.32	1.6	499	306

catchment is from south to north along Chisholm Avenue and Main Street to Lumsden Avenue and then northward to Massey Creek, a tributary of the Don River, through a 1.83 m (6 ft) diameter outfall. The drainage area covers 22.7 hectares (56 acres). Originally, the sewer system in the catchment was of the combined type but the system was separated in the '60's with the addition of storm sewers, the old combined sewers remaining as sanitary sewers. Whereas all catch basins are connected to the new storm system, virtually all roof drains are connected to the old combined sewer. Only 17.4 hectares of the total 22.7 hectares contributed runoff to the modified storm sewer system.

The land use in the catchment is almost entirely single family residential, with the exception of five or six corner stores. The houses are 50 to 70 years old with few exceptions.

Soil borings in the catchment to a depth of 10 to 12 metres revealed only coarse to fine sand with no trace of underlying clay till or the water table.

A physical description of the Broadview catchment follows before the discussion of the Barrington study results, since both Barrington and Broadview were studied under the same project, the results applying to both catchments.

3. East York - Broadview Catchment [9]

The Broadview catchment is located in the southwest corner of the Borough of East York in Metropolitan Toronto. Drainage in the catchment is from north to south along Broadview Avenue to Nealon Avenue, then westward through a 244 cm (96 in) diameter outfall to the Don River. The drainage area covers 25.34 hectares (62.6 acres). Originally, the sewer system in the catchment was of the combined type but the system was separated in the '60's with the addition of storm sewers, the old combined sewers remaining as sanitary sewers. All road catch basins are connected to the storm sewer system as well as the storm services from the relatively new high-rise apartments and supermarket. With few exceptions, the roof drainage from all of the houses is still connected to the old combined sewers. Only 22.0 ha (54.3 acres) of the total area contribute runoff to the modified storm sewer system.

The land use in the catchment is predominantly single family residential with a small portion of multiple family residential consisting of several high-rise apartment buildings. Commercial land use comprises a supermarket, two service stations, an automobile dealer, a take-out food store, and several small neighbourhood stores. Buildings vary in age from 80 or more years old to new high-rise.

The soil in the catchment is 2 to 3 metres (6.6 to 9.8 ft) of silty fine sand overlaying blue clay. The water table is perched at the interface between the sand and clay and does not appear to penetrate into the clay.

Both the Barrington and Broadview catchments were established and monitored by the Borough of East York under contract with the Urban Drainage Subcommittee, the objective being to characterize the quantity and quality of storm runoff.

Runoff flows in both catchments were measured by means of a calibrated vertical slot weir. Storm water samples were collected manually and automatically at 5 to 15 minute intervals and analyzed for up to 20 parameters.

Table A-5 indicates the total mass, maximum concentration and flow weighted mean of selected runoff constituents for each storm event monitored. Table A-6 summarizes the bacterial concentrations observed for each storm event. The relatively high concentration of pollutants in storm water can be attributed to the minor character of the events observed and to the absence of roof runoff. That is, Barrington and Broadview storm sewers carry mostly the highly polluted runoff from the streets without any dilution by the less polluted runoff from roofs.

Additional quality data are available in a report to the Urban Drainage Subcommittee by G. Mills [9]. A further continuation of the study is under consideration.

4. Malvern Catchment [8, 20]

The Malvern catchment was established, instrumented and monitored by the Hydraulics Research Division of the Canada Centre for Inland Waters. The project has been co-sponsored by the Urban Drainage Subcommittee with the objective of collecting prceipitation-runoff data.

TABLE A-5. EAST YORK CATCHMENTS [9]

Total Mass, Maximum Concentration and Flow Weighted Mean of Selected Runoff Constituents

STORM	No. Samples	Duration (hours)	Time Between Samples (hours)	SUSPENDED SOLIDS Total Flow Volume (m^3)	Total Mass (kg)	Maximum Suspended Solids (mg/l)	Flow Weighted Mean (mg/l)
BROADVIEW							
July 29, 1974	11	1.67	0.167	155.59	7.8867	80	50.790
November 5, 1974	12	1.83	0.167	221.06	23.2050	110	105.181
November 20, 1974	11	1.67	0.167	297.71	69.0583	400	232.426
BARRINGTON							
May 8, 1974	24	1.92	0.083	63.99	3.3817	60	52.637
May 16, 1974	12	1.83	0.167	223.23	17.6117	120	79.054
June 10, 1974	5	2.00	0.500	311.91	78.8900	400	253.047
June 13, 1974	11	1.67	0.167	311.66	29.0750	100	93.487
June 18, 1974	5	2.00	0.500	511.56	25.6300	115	50.102
July 29, 1974	24	1.92	0.083	190.96	47.7417	630	249.005
September 12, 1974	12	1.83	0.167	196.71	14.8967	100	75.880
September 17, 1974	12	1.83	0.167	237.77	17.9500	100	75.643
September 25, 1974	12	1.83	0.167	200.68	20.6767	170	103.239
November 5, 1974	12	1.83	0.167	80.44	25.2667	400	314.732
November 20, 1974	11	1.67	0.167	93.61	3.8867	220	41.604
January 29, 1975	4	1.50	0.500	199.62	20.8450	195	104.423
August 21, 1975	8	1.75	0.250	161.55	11.0100	100	68.152
September 11, 1975	5	2.00	0.500	173.34	16.5800	160	95.650
October 1, 1975	8	1.75	0.250	200.48	26.6725	195	133.046
November 7, 1975	8	1.75	0.250	106.61	7.7675	100	72.862
December 30, 1975	8	1.75	0.250	111.83	32.3500	340	289.291
January 26, 1976	8	1.75	0.250	249.48	40.3500	295	161.736
February 18, 1976	7	1.50	0.250	145.04	25.5500	180	176.164

TABLE A-5. (CONT'D)

STORM	COD Total Flow Volume (m³)	COD Total Mass (kg)	COD Maximum COD (mg/l)	COD Flow Weighted Mean (mg/l)	PHENOLIC COMPOUNDS Total Flow Volume (m³)	PHENOLIC COMPOUNDS Total Mass (kg)	PHENOLIC COMPOUNDS Maximum Phenolic Compounds (mg/l)	PHENOLIC COMPOUNDS Flow Weighted Mean (mg/l)
BROADVIEW								
July 29, 1974	155.59	15.435	120	99.616	155.59	0.310	0.002	0.00199
November 5, 1974	221.06	16.947	120	72.814	221.06	0.352	0.003	0.00159
November 20, 1974	297.71	58.267	490	195.937	297.71	1.701	0.007	0.00573
BARRINGTON								
May 8, 1974	63.99	6.177	120	96.155	63.99	0.573	0.027	0.00892
May 16, 1974	223.23	18.918	120	84.194	223.23	0.699	0.0095	0.00314
June 10, 1974	311.76	56.300	700	541.763	311.76	12.060	0.048	0.03870
June 13, 1974	311.66	55.900	320	179.720	311.66	7.503	0.054	0.02412
June 18, 1974	511.56	22.975	160	44.912	511.56	0.567	0.003	0.00110
July 29, 1974	190.96	70.417	740	367.270	190.96	2.634	0.030	0.01374
September 12, 1974	196.71	77.717	790	395.867	196.71	5.287	0.049	0.02693
September 17, 1974	237.77	81.933	440	345.273	237.77	3.051	0.020	0.01286
September 25, 1974	200.68	103.200	810	515.279	200.68	8.382	0.100	0.04185
November 5, 1974	80.44	56.217	880	700.257	80.44	8.740	0.145	0.10887
November 20, 1974	93.61	2.808	40	30.061	93.61	0.366	0.004	0.00392
January 29, 1975	199.98	21.015	140	105.086	199.62	2.178	0.012	0.01091
August 21, 1975	-	-	-	-	161.55	3.900	0.042	0.02414
October 1, 1975	200.48	46.588	310	232.386	200.48	1.700	0.013	0.00848
November 7, 1975	106.61	26.750	310	250.926	106.61	1.839	0.070	0.01726
December 30, 1975	111.85	77.475	910	692.824	111.83	6.258	0.065	0.05596
January 26, 1976	249.48	130.250	770	522.086	249.48	13.760	0.075	0.05515
February 18, 1976	161.87	25.725	175	158.929	161.87	2.820	0.030	0.02613

TABLE A-5. (CONT'D)

STORM	TOTAL PHOSPHORUS Total Flow Volume (m^3)	Total Mass (kg)	Maximum Total Phosphorus (mg/l)	Flow Weighted Mean (mg/l)	BOD Total Flow Volume (m^3)	Total Mass (kg)	Maximum BOD (mg/l)	Flow Weighted Mean (mg/l)
BROADVIEW								
July 29, 1974	155.59	0.0431	0.40	0.278	155.59	2.2313	19	14.3707
November 5, 1974	201.28	0.0712	0.80	0.354	221.06	2.1950	48	9.9490
November 20, 1974	292.42	0.1689	1.00	0.579	297.71	6.8317	38	22.9930
BARRINGTON								
May 8, 1974	89.46	0.0438	0.60	0.489	63.99	1.6363	26	25.470
May 16, 1974	219.50	0.0895	0.80	0.409	223.23	5.4067	30	24.269
June 10, 1974	158.69	0.4590	4.00	2.881	311.76	53.1500	260	170.484
June 13, 1974	319.00	0.5590	3.00	1.756	311.66	13.8083	85	44.304
June 18, 1974	450.53	0.1692	0.60	0.374	511.56	2.3333	11	4.562
July 29, 1974	243.54	0.3429	1.70	1.408	190.96	15.9550	160	83.216
September 12, 1974	208.20	0.1709	1.20	0.823	196.71	29.7950	280	151.786
September 17, 1974	241.50	0.1457	0.72	0.605	237.77	36.8433	220	155.261
September 25, 1974	193.17	0.1966	1.60	1.020	200.68	35.9533	320	179.515
November 5, 1974	84.20	0.2293	3.80	2.730	80.44	15.1033	220	188.133
November 20, 1974	93.61	0.0216	0.32	0.232	93.61	0.8650	75	9.259
January 28, 1975	199.98	0.1155	0.80	0.578	199.62	6.3500	46	31.810
August 21, 1975	161.55	0.0319	2.00	0.197	161.55	8.5575	110	52.971
September 11, 1975	158.72	0.3068	11.00	1.933	275.40	10.6700	160	38.744
October 1, 1975	200.03	0.1704	1.40	0.852	200.48	8.9525	65	44.656
November 7, 1975	106.61	0.1056	1.70	0.991	106.61	5.8975	85	55.321
December 30, 1975	111.83	0.0464	0.56	0.415	111.83	4.6075	45	41.203
January 26, 1976	249.48	0.0829	0.49	0.332	249.48	4.7725	24	19.130
February 18, 1976	161.87	0.0588	0.42	0.364	161.87	1.0543	7	6.513

TABLE A-5. (CONT'D)

STORM	NITRITE Total Flow Volume (m^3)	NITRITE Total Mass (kg)	NITRITE Maximum Nitrite (mg/l)	NITRITE Flow Weighted Mean (mg/l)	NITRATE Total Flow Volume (m^3)	NITRATE Total Mass (kg)	NITRATE Maximum Nitrate (mg/l)	NITRATE Flow Weighted Mean (mg/l)
BROADVIEW								
July 29, 1974	322.60	0.0139	0.14	0.090	155.60	0.2432	2.1	1.566
November 5, 1974	-	-	<0.04	-	-	-	<0.4	-
November 20, 1974	292.42	0.0248	0.12	0.085	-	-	0.8	-
BARRINGTON								
May 8, 1974	111.96	0.0216	0.30	0.193	50.91	0.0217	1.5	0.425
May 16, 1974	-	-	<0.02	-	-	-	<0.2	-
June 10, 1974	-	-	<0.02	-	-	-	<0.2	-
June 13, 1974	-	-	<0.02	-	-	-	<0.2	-
June 18, 1974	402.57	0.0081	0.02	0.020	-	-	0.4	-
July 29, 1974	199.62	0.0076	0.26	0.038	-	-	1.9	-
September 12, 1974	97.03	0.0026	0.04	0.027	-	-	<0.2	-
September 17, 1974	-	-	<0.02	-	-	-	<0.2	-
September 25, 1974	149.33	0.0031	0.21	0.021	-	-	<0.2	-
November 5, 1974	-	-	<0.04	-	-	-	<0.4	-
November 20, 1974	-	-	0.04	-	-	-	0.8	-
January 29, 1975	199.98	0.0095	0.06	0.047	-	-	<0.2	-
August 21, 1975	-	-	0.24	-	-	-	1.0	-
September 11, 1975	-	-	0.90	-	-	-	0.26	-
October 1, 1975	200.03	0.0701	0.66	0.351	144.50	0.0938	1.0	0.649
November 7, 1975	-	-	0.12	-	-	-	<0.2	-
December 30, 1975	111.83	0.0440	0.42	0.393	111.83	0.1450	1.6	1.297
January 26, 1976	-	-	0.44	-	-	-	2.1	-
February 18, 1976	161.87	0.0163	0.14	0.101	161.87	0.2165	1.5	1.338

TABLE A-5. (CONT'D)

STORM	TOTAL KJELDAHL Total Flow Volume (m^3)	Total Mass (kg)	Maximum Total Kjeldahl (mg/l)	Flow Weighted Mean (mg/l)	CHLORIDES Total Flow Volume (m^3)	Total Mass (kg)	Maximum Chlorides (mg/l)	Flow Weighted Mean (mg/l)
BROADVIEW								
July 29, 1974	155.59	0.3003	2.5	1.934	155.59	11.03	84	71.02
November 5, 1974	201.28	0.2607	2.5	1.298	201.28	3.97	45	19.75
November 20, 1974	292.42	1.0422	7.5	3.571	292.42	5.80	61	19.86
BARRINGTON								
May 8, 1974	89.46	0.1850	2.5	2.068	89.46	1.67	20	18.64
May 16, 1974	219.50	0.3387	2.5	1.551	219.50	1.66	10	7.59
June 10, 1974	158.69	1.7348	16	10.888	158.69	5.04	57	31.62
June 13, 1974	319.00	1.6357	11	5.138	317.00	5.96	27	18.73
June 18, 1974	450.53	0.7860	3	1.738	450.53	2.03	5	4.49
July 29, 1974	243.54	1.5185	10	6.235	243.54	14.67	84	60.22
September 12, 1974	208.20	1.1422	8	5.497	208.20	3.36	26	16.15
September 17, 1974	241.50	0.8652	4.4	3.590	241.50	2.51	13	10.43
September 25, 1974	193.17	1.3198	10	6.846	193.17	4.36	31	22.59
November 5, 1974	84.20	0.5048	8	6.008	84.20	3.26	64	38.76
November 20, 1974	93.61	0.0770	1.0	0.824	93.61	3.09	66	33.02
January 29, 1975	199.98	0.8333	6	4.167	199.98	44.40	255	222.02
August 21, 1975	161.55	0.9269	15	5.737	161.55	8.89	125	55.04
September 11, 1975	158.72	1.3190	20	8.311	275.40	8.56	107	31.09
October 1, 1975	200.03	0.5383	4.7	2.691	200.03	9.98	34	24.93
November 7, 1975	106.61	0.2270	6.5	2.129	106.61	4.09	33	19.18
December 30, 1975	111.83	0.2860	3.3	2.558	111.83	654.50	7075	5855.13
January 26, 1976	249.48	1.6398	10.0	6.573	249.48	140.00	5885	4569.50
February 18, 1976	161.87	0.3603	2.6	2.226	161.87	14.38	127	88.84

TABLE A-5. (CONT'D)

STORM	LEAD Total Flow Volume (m^3)	Total Mass (kg)	Maximum Lead (mg/l)	Flow Weighted Mean (mg/l)
BROADVIEW				
July 29, 1974	155.59	0.0489	0.46	0.315
November 5, 1974	221.06	0.0740	-	0.335
November 20, 1974	297.71	0.2501	-	0.845
BARRINGTON				
May 8, 1974	111.91	0.0502	0.67	0.448
May 16, 1974	219.50	0.0668	0.50	0.305
June 10, 1974	311.76	0.3611	1.70	1.158
June 13, 1974	311.66	0.1734	0.64	0.557
June 18, 1974	511.56	0.1543	0.64	0.302
July 29, 1974	-	-	-	-
September 12, 1974	288.90	0.1485	0.67	0.514
September 17, 1974	311.58	0.0906	0.47	0.291
September 25, 1974	200.68	0.0939	0.87	0.469
November 5, 1974	80.44	0.1117	1.80	1.391
November 20, 1974	93.61	0.0163	1.80	0.175
January 29, 1975	155.34	0.0752	0.80	0.484
August 21, 1975	161.55	0.0741	0.73	0.458
October 1, 1975	200.48	0.1226	0.89	0.611
November 7, 1975	100.94	0.0492	0.59	0.487
December 30, 1975	111.83	0.1563	1.60	1.397
January 26, 1976	249.48	0.2302	1.50	0.923
February 18, 1976	161.87	0.1517	1.00	0.937

TABLE A-6. MICROBIOLOGICAL RESULTS - EAST YORK CATCHMENTS [9]

	Date	Fecal Coliforms	Enterococcus	Background Colonies	Coliform Bacteria	
		All figures are (Bacterial Count per 100 ml) X 10^6				
BROADVIEW	September 17, 1973	0.005 - 0.015	0.0031 - 0.0062	-	0.11 - 0.75	a
	November 21, 1973	0.001 - 0.42	0.0049 - 0.034	-	0.01 - 1.76	a
	November 5, 1974	0.0013 - 0.008	<0.015 - 0.033	.303 - 1.4	0.057 - 0.11	b
	November 20, 1974	0.0057 - 1.1	0.0043 - 0.063	.077 - 4.3	0.037 - 4.7	b
BARRINGTON	May 8, 1974	0.0021 - 0.15	0.0072 - 0.0224	<1.5 - 3.8	0.09 - 1.82	a
	June 10, 1974	0.30 - 1.16	>0.15 - 10^6	>0.15 - 10^6	>1.5 - 10^6	b
	June 13, 1974	0.26 - 2.4	0.053 - 0.310	73 - 387	43 - 193	b
	June 18, 1974	0.076 - 0.11	0.0106 - 0.050	1.05 - 2.9	.193 - .83	b
	July 29, 1974	0.03 - 0.19	0.160 - 0.430	8.5 - 30	3.5 - 16.9	b
	September 12, 1974	0.05 - 0.49	0.061 ->0.15	12 - 75	8.9 - 17	b
	September 17, 1974	0.06 ->0.15	0.107 - 0.383	4.3 ->15	1.3 ->15	b
	September 25, 1974	<.01 - 0.28	<0.010 - 1.55	<15 - 30	1.8 - 20.3	b
	November 5, 1974	0.05 - 0.33	0.147 - 1.4	21 - 55	2.3 - 7.6	b
	November 20, 1974	<.01 - 0.08	0.130 - 0.140	<.1 - .37	<.1 - .1	b
	August 21, 1975	0.004 - 0.31	0.042 - 0.183	3.1 - 7.1	.07 - 1.57	b
	September 11, 1975	0.02 - 1.4	0.030 - 0.330	13 - 110	.46 - 6.6	b

a - results of 1 sample   b - average of 3 samples

The Malvern catchment is located in Burlington, Ontario. Drainage in the catchment is from the north corner towards the outfall located in the southwest corner, the drainage area covering 23.3 hectares (57.6 acres). The elevation ranges from about 83 to 90 m (272 ft-295 ft) above sea level and the surface slopes are gentle, in the order of 0.7% to 1.0%.

The catchment is served by a tree-type, converging separate sewer system, connected by roof leaders. The sewers are made of standard concrete pipes. There is a total of 270 catch basins in the catchment, the density being 3 C.B./ha (1.21 C.B./acre). The system is relatively new and in good condition.

The population of the catchment was estimated in 1974 at 1,000 (43.3 p/ha). The land use is entirely single family residential. The 214 houses located within the catchment boundaries were built in the early '60's, with virtually all development completed by 1964. There are no vacant lots or parks in the area and all properties are well maintained. The catchment total gross imperviousness is 34%, with streets accounting for 2.71 ha (6.68 acres), driveways 1.26 ha (3.11 acres), sidewalks 0.66 ha (1.63 acres) and roofs 3.28 ha (8.1 acres). Thirty-one percent of the catchment area is directly connected to the sewer system. The soil is described as fox sandy loam, of shallow phase and well drained. The street sweeping frequency in Malvern catchment is once every two weeks.

Storm water quality was monitored by automatically collecting samples sequentially at 5 to 10 minute intervals. The samples were analysed for a number of water quality parameters. However, complete data were available only for the following four parameters, as indicated in Table A-7: COD, nitrates plus nitrites (N), total phosphorus (P), and suspended solids (SS). The relatively high concentrations of nitrogen and phosphorus shown in Table A-7 indicate that rainfall could be a significant source of these pollutants. A multivariate analysis conducted by Marsalek [8] detected a strong dependence of the pollutant loadings on the antecedent dry period. No physically meaningful relationship was found between the total loadings and the total runoff volume, rainfall intensity, and antecedent storm rainfall. Hydrological studies relating to the catchment are expected to continue until 1978.

TABLE A-7. FLOW WEIGHTED AVERAGE CONCENTRATIONS MALVERN, BURLINGTON, SUMMER 1975 [8]

Event No.	N (mg/l)	COD (mg/l)	P (mg/l)	SS (mg/l)
101	1.91	49.8	0.13	11.8
102	1.19	119.6	0.51	--
103	1.86	118.6	0.36	97.6
104	2.73	53.5	0.30	63.3
105	3.52	80.5	0.22	60.7
106	0.65	23.0	0.09	8.8
107	1.22	23.0	0.08	27.4
108	2.76	66.2	0.22	25.0
109	1.04	25.6	0.06	20.1
110	1.39	43.2	0.29	63.0
111	1.65	69.7	0.28	39.4
112	2.14	55.8	0.46	194.8
113	1.98	26.1	0.07	9.8
114	0.91	35.7	0.11	17.0
115	1.32	22.0	0.08	9.0
116	0.07	25.0	0.01	6.8
Observed range:				
Min.	0.02	5.3	0.01	2.8
Max.	11.00	312.0	1.50	681.0

Note:

N is given as nitrates + nitrites.

5. Aldershot Catchment [16, 17, 33]

This catchment is a 6.9 hectare (17.0 acres) commercial plaza that is 100% impervious. Limited observations of precipitation, runoff flow rate and runoff quality were made on the catchment.

Table A-8 indicates the arithmetic mean concentrations and observed range of values for several pollutants for two storms monitored in the summer of 1975. Table 9 (main text) compares the arithmetic average of concentrations for these two storms with the corresponding arithmetic average of concentrations in Malvern catchment. Table 9 reveals that the nitrogen (nitrites plus nitrates) concentration of the storm water runoff is four to five times greater in the Malvern-residential area than the Aldershot-commercial area while the reverse trend is apparent for COD, phosphorus, suspended solids and lead. That is, their concentration is higher by a factor of one to six in the Aldershot-commercial area than in the Malvern-residential area.

6. North Guelph (54") Catchment [18]

The North Guelph catchment is located in Guelph, Ontario in the vicinity of Victoria Road and Woodlawn Road at the northeast end of the city. Drainage in the catchment is from the southeast corner north and west towards the 137 cm diameter (54 in) outfall located on the Speed River, the drainage area covering 58.8 hectares (145.5 acres). The elevation ranges from about 348-355 m (1,140 ft-1,165 ft) above sea level and the surface slopes are moderate, in the order of 3%. The catchment, is primarily single family residential.

The catchment is served by a tree-type, separate storm sewer system, directly connected to roof leaders. The system is basically an elongated area with a main trunk running through the centre of the catchment. There is an estimated total of 225 catch basins in the catchment, the density being 3.7 C.B./ha (1.5 acre). The system is relatively new and in good condition.

The land use in the catchment is primarily residential (86.9%) but includes institutional (3.7%, one school), commercial (2.1%, one shopping plaza) and open space (7.3%), as well. Most of the residential

TABLE A-8. OBSERVED RANGE AND MEAN OF CONCENTRATIONS AS MEASURED IN ALDERSHOT, BURLINGTON [33]

Quality Parameter	Arithmetic Mean Concentration (mg/l)	Range (mg/l)
Nitrogen (nitrate & nitrite)	0.370	0.010 - 1.20
Total Phosphorous	1.11	0.045 - 5.4
COD	120.8	12.4 - 490
Suspended Solids	117.9	4.0 - 380
Lead	0.45	0.05 - 1.3

no. of samples = 27

land use is single family, although a small portion is multiple family consisting of small apartment buildings and townhouses. The subdivision was constructed in the late '60's.

The catchment total net imperviousness is 35.7%. Since sidewalks were not included, the total net imperviousness represents the fractional impervious area which is directly connected to the sewer system. The pervious soil is described as Guelph loam.

The street sweeping frequency in North Guelph catchment is estimated at once every 30 days for local streets (with an exception of two main streets, which are swept about once a week).

A physical description of the West Guelph (138") catchment is included before the discussion of the results of storm water runoff studies conducted in both Guelph catchments.

7. West Guelph (138") Catchment [21]

The West Guelph catchment is located in Guelph, Ontario. The catchment is 235 ha (580 acres) with elevation ranges from 323 to 345 m (1060 ft-1130 ft) above sea level.

The catchment is serviced by a separate sewer system completed in the early '70's, except for the Speedvale Street section, which was completed in the summer of 1976.

The most predominant land use type in the test catchment is the single family residential with 47% of the total area. Other types are open space (23%), industrial (17%), and multiple family residential (13%). The institutional area comprises two schools and the commercial area consists of a small shopping plaza. Due to their sizes, these two areas were considered as part of the residential land use. Almost 50% of the residential area dates back to the early 1930's, the other 50% being constructed in the later '60's. Roof leaders are connected to the separate storm sewers in the relatively newer houses, but the majority of older houses are not connected.

The total gross imperviousness of the catchment is estimated at approximately 36.8%. Weather permitting, the streets are cleaned once a month. The land has a gentle slope and the northwest corner of the catchment (which is a mixture of open space and industrial land use) is drained by ditches along the major roads.

The monitoring of the Guelph catchment was carried out between July, 1975 and June, 1976 for the North Guelph catchment and until November, 1976 for the West Guelph catchment. Quality data were collected manually and automatically at 5 and 15 minute intervals, respectively. During this period, eight storms were monitored for the 138" catchment. Table A-9 summarizes the storm water runoff quality data obtained. From this table, it is evident that the bacteriological concentrations are significtly higher at the West catchment. The much higher bacteriological concentrations in this catchment can be attributed to several factors. The West catchment is an older area with a greater percentage of industrial land use. Much of the 23% of open space in the West catchment (as compared to only 7.3% in the North catchment) is lowland, some of which contributes a relatively large amount of poor quality baseflow to the sewer system. Finally, contributions from fugitive sources are greater in the West catchment, due to the increased amount of industrial and other urban activities.

8. Windsor "A" Catchment [19]

The Windsor "A" catchment is located within the predominantly industrial city of Windsor. The 12 hectare (29.7 acre) catchment has a population of approximately 600 people. This catchment is serviced by separate storm sewers with average slopes between 0.25% and 0.30%. The system drains through a 53 cm diameter outfall (21 in) into Lake Erie via the Detroit River.

The land use is primarily single family residential with most housing units being 25 to 30 years old. The land is relatively flat with less than one foot of clay top soil overlying a hard, brown, impervious clay soil. The street asphalt is worn and broken and runoff likely contains a large number of solids.

At this site, 25 storms were monitored by the Department of Civil Engineering, University of Windstor. A Testing Machines International Sampler collected hourly samples and flow was calculated by recording the water level. Table A-10 indicates the observed range and average quality. The seasonal and annual loadings for 13 parameters are shown in Table A-11. Table A-12 shows the hourly loadings for 14 pollutants.

TABLE A-9. GUELPH CATCHMENTS STORM WATER RUNOFF PARAMETERS JULY, 1975 - JUNE, 1976 [8, 21]

PARAMETER	NORTH CATCHMENT			WEST CATCHMENT		
	Range of Concentrations (mg/l)	Range of Flow Weighted Mean Concentrations (mg/l)	# of Samples	Range of Concentrations (mg/l)	Range of Flow Weighted Mean Concentrations (mg/l)	# of Samples
BOD_5	0.2-60	7.84-17.71	99	0.6-95	2.27-14.93	40
COD	18-320	60.00-89.44	99	20-200	43.25-167.96	40
Solids						
Total	72-2300	363.93-563.90	99	153-780	135.50-1334-64	40
Suspended	10-1090	87.2-159.21	99	5-352	55.20-301.43	40
Phosphorous						
Total	0.04-1.6	0.249-0.349	99	0.04-1.10	0.133-0.220	40
Soluble	0.004-0.072	0.020-0.028	99	0.002-0.06	0.015-0.040	40
Nitrogen						
Free Ammonia	<0.01-0.6	0.172-0.220	99	0.01-1.10	0.10-0.289	40
Kjeldahl	0.4-5.3	1.63-3.08	99	0.2-15	0.867-204	40
Nitrite	0.01-0.22	0.059-0.097	99	0.007-1.80	0.02-0.115	40
Nitrate	<0.2-46	0.593-1.05	99	0.01-1.70	0.358-3.65	40
Chloride	1-68	21.60-66.65	49	7.8-103	3.0-57.6	40
Conductivity (umhos/cm)	64-2230	340.92-730.14	99	149-860	85.7-1871.8	40
Coliforms (MPN/100 ml)						
Total	<10,000-830,000		49	60,000-13,800,000		40
Fecal	< 1,000- 71,000		49	5,477-570,000		40
Streptococcus	3,000- 69,000		49	3,000-36,000		40

TABLE A-10. WINDSOR "A" CATCHMENT [9]

Observed Average Quality of Runoff(1)

Constituent	Annual Mean	Range	Standard Deviation	Winter Mean	Spring Mean	Summer Mean	Fall Mean
BOD, mg/ℓ	20.5	0-78.4	14.0	17.7	20.8	26.8	18.2
Total Coliform, (#/100 ml) x 10^{-3}	64	0.2-1200	170	4.0	16.0	270	26
Fecal Coliform, (#/100 ml) x 10^{-2}	82	0.1-2000	270	6.9	39.0	350	9.2
TSS, mg/ℓ	279	23-1230	245	278	467	384	111
VSS, mg/ℓ	112	0-392	92	129	97	138	36
Ammonia, mg/ℓ(2)	0.054	0-0.710	0.077	0.033	0.050	0.050	0.085
Nitrates, mg/ℓ(2)	1.16	0-4.70	0.74	1.05	1.14	1.37	1.14
Nitrites, mg/ℓ(2)	0.066	0.001-.570	0.066	0.066	0.070	0.094	0.045
Orthophosphates, mg/ℓ	0.437	0-2.500	0.444	0.299	0.634	0.601	0.316
Chlorides, mg/ℓ	72	4-1585	166	122	48	29	59
Sulfates, mg/ℓ	46.0	1-220	38.5	56.8	34.5	37.8	46.2
Phenolphthalein Alkalinity, mg/ℓ(3)	0	0	0	0	0	0	0
Total Alkalinity, mg/ℓ(3)	115	40-344	62	123	120	108	108
Calcium Hardness, mg/ℓ(3)	100	40-272	46	108	97	102	92
Total Hardness, mg/ℓ(3)	151	55-504	98	158	131	142	163
pH(4)	7.40	6.75-8.02	0.23	7.50	7.39	7.30	7.37
Colour, Unit	160	45-440	82	204	144	99	--
Turbidity, JT4	363	50-1200	225	360	414	304	--
Sp. Conductance, milli-mhos/cm	0.352	0.065-2.390	0.312	0.425	0.295	0.294	0.343
Grease and Oil, mg/ℓ	18.7	8.9-39.0	--	15.1	17.9	24.3	19.2
Temperature, °C	10.9	4.0-18.5	--	5.3	10.9	14.9	12.8

(1) Samples for discharge less than 0.28 ℓ/sec not included.

(2) mg/ℓ as N.

(3) mg/ℓ as $CaCO_3$.

(4) Arithmetic means, range and std. deviation.

TABLE A-11. WINDSOR "A" CATCHMENT [19]

Seasonal and Annual Constituent Loadings[(1), (3)]
in kg /ha

Constituent	Winter	Spring	Summer	Fall	Annual
BOD	3.2	9.6	6.8	4.5	24.1
TSS	125.6	294.5	147.9	41.9	609.9
VSS	50.1	93.1	39.4	15.8	198.4
Ammonia as N	0.009	0.031	0.016	0.011	0.067
Nitrate as N	0.251	0.460	0.354	0.194	1.259
Nitrite as N	0.018	0.030	0.020	0.010	0.078
Orthophosphates	0.096	0.299	0.173	0.083	0.651
Chlorides	19.3	13.8	5.3	37.0	75.4
Sulfates	11.9	11.1	8.7	7.1	38.8
Total Alkalinity as $CaCO_3$	36.2	54.2	29.7	19.4	139.5
Calcium Hardness as $CaCO_3$	27.9	35.3	26.6	16.7	106.5
Total Hardness as $CaCO_3$	38.2	44.8	35.4	28.3	146.7
Grease and Oil[(2)]	--	--	--	--	20.1

(1) Storms of Oct. 21, Nov. 25-26, and Jan. 23-24 not included.

(2) Estimated.

(3) Samples with discharge less than 0.25 ℓ/sec not included.

TABLE A-12. WINDSOR "A" CATCHMENT [19]

Average Hourly Constituent Loads for the Year(1),(2)
in kg/hr

Constituent	HOUR 1	2	3	4	5	6	7	8
BOD	1.27	0.59	0.50	0.59	0.59	0.27	0.50	0.23
Total Coliform x 10^{-9} (3)	120	220	62	66	130	24	220	40
Fecal Coliform x 10^{-8} (3)	104	350	74	120	160	32	290	21
TSS	36.2	22.1	10.2	20.7	12.5	8.4	12.6	2.4
VSS	7.1	5.1	2.7	5.0	2.7	2.0	2.7	1.4
Ammonia as N	0.0037	0.0015	0.0010	0.0029	0.0019	0.0014	0.0007	0.0002
Nitrate as N	0.046	0.043	0.034	0.032	0.020	0.020	0.021	0.013
Nitrite as N	0.0037	0.0029	0.0022	0.0022	0.0020	0.0011	0.0012	0.0006
Orthophosphates	0.035	0.035	0.014	0.012	0.020	0.008	0.009	0.005
Chlorides	2.0	2.5	2.0	1.7	0.7	0.9	2.2	0.5
Sulfates	1.5	1.2	1.0	1.2	0.7	0.7	1.3	0.5
Total Alkalinity as $CaCO_3$	7.1	5.0	2.7	5.0	2.7	2.0	2.7	1.4
Calcium Hardness as $CaCO_3$	4.5	3.5	2.2	3.3	1.9	1.9	2.7	1.5
Total Hardness as $CaCO_3$	5.9	4.6	3.2	4.9	2.4	2.5	3.5	1.8

(1) Storms of Oct. 21, Nov. 25-26, Jan. 23-24 not included.

(2) Samples with less than 0.28ℓ/sec discharge, not included.

(3) Listed as #/hr.

9. Windsor "B" Catchment

The Windsor "B" catchment is located within Windsor City Limits (pop. 200,000). This catchment covers an area of 36 hectares (89 acres) with a population density of approximately 25 persons per ha (10 persons per acre, total of 900 people). The sewer system is separated and discharges through a 137 cm diameter outfall (54 in) into the Great Lakes via the Detroit River.

The land use in this catchment is predominantly single family residential with one park, school, and multifamily complex. The land is relatively flat with surface grades not exceeding 2%.

A large manhole of the 137 cm outfall pipe was used to house sampling equipment. Water level was continuously monitored by an Arkan Water Level Recorder. Sequential quality samples were taken by an automatic sampler. In Table A-13 the seasonal means, annual means and range for 18 parameters are shown.

10. Carling Street Catchment [12, 13]

The Carling Street catchment is located in the oldest part of urban London, Ontario. Drainage in the catchment is from the northeast corner westward toward the outfall on the North Thames River, with a drainage area covering 45 hectares (112 acres). The surface slopes are gentle, in the order of 0.4% to 0.8%.

The catchment is served by a separate sewer system which dates back to 1916, except for 136 metres of Queens Street built in the mid-60's. This basin is situated on a high alluvial terrace.

The population is 2,800, a density of 62.2 persons per hectare. A variety of land uses are represented in the catchment: residential occupies 14% of the land area, industrial 27%, commercial 19%, institutional 14%, grassed parkland 9% and impermeable road surface 15%. The total gross imperviousness is 65%. Street cleaning in the summer is conducted every other day on arterial roads; however, cleaning frequency on minor roads is usually greater than two weeks.

Water quality data were sampled automatically or manually, taken as spot or sequential, depending on the nature of the runoff-storm events, baseflow, and snowmelt. Preliminary results from the study

TABLE A-13. WINDSOR "B" CATCHMENT - AVERAGE CONCENTRATIONS OF RUNOFF CONSTITUENTS [11]

Constituent	Winter Mean	Spring Mean	Summer Mean	Fall Mean	Annual Mean	Range
Colour (app.), units	134	419	177	151	220	30-1650
Turbidity, J.T.U.	76	249	118	91	134	14-1020
Sp. conductance milli mhs/cm	1.18	0.33	0.35	0.46	0.58	0.12-7.70
*pH	7.22	7.43	7.45	7.39	7.35	6.30-8.70
T.S.S., mg/l	94	741	297	86	305	2-4122
V.S.S., mg/l	39	90	47	22	59	0-350
Total alkalinity, mg/l	90	100	125	110	106	8-232
Total hardnessm mg/l	199	146	205	292	211	48-585
Calcium hardness, mg/l	138	110	136	190	144	40-348
Chloride, mg/l	345	27	33	36	110	4-2580
Orthophosphate, mg/l	1.42	1.94	0.32	0.24	0.98	0-34
Sulfate, mg/l	100	64	97	165	106	32-325
Ammonia, mg/l	0.075	0.134	0.115	0.025	0.087	0-1.80
Nitrite, mg/l	0.06	0.11	0.16	0.04	0.09	0.01-0.53
Nitrate, mg/l	1.33	2.64	0.82	0.81	1.40	0.05-6.30
B.O.D., mg/l	9	8	16	16	12	2-52
Total coliform/100 ml	263,530	5,730,430	2,998,500	630,834	2,405,800	1400-17, 750,000
Fecal coliform/100 ml	23,400	10,970	490	160	8,760	0-230,000

* These means are the arithmetic mean of observed pH values.

indicate that baseflow, supplemented by anthropogenic (man-made) inputs, may be a significant contributor to both water quality and flow in sewered catchments in a downtown area [12].

The water quality data for baseflow for this catchment are presented in Table A-14. "The common anthropogenic inputs appear to have significant effects on the water quality of storm runoff events. This can be demonstrated by considering the first three examples in Figure A-1. The data are summarized in Table A-15, including snowmelt. The study also shows that pollutants (from anthropogenic inputs during dry weather flows) such as phosphorus enriched material within the sewer system enhances the first flush effect of storm water runoff" [12].

Monitoring is being extended to 1977. Further sampling within the catchment should provide additional information as to the source and the magnitude of pollution being washed off the urban area throughout the separate storm drainage.

11. Kitchener-Schneider's Creek Catchment and Montgomery Creek Catchment

Schneider's Creek drains the western portion of Kitchener-Waterloo. The drainage basin covers an area of 3,580 hectares (8,850 acres). The population density is 16.8 p/ha (6.7/acre) and the population is approximately 60,000. Land use in the Schneider's Creek basin is primarily single family residential and agricultural which account for 42% and 34%, respectively, of the total area. Forests, industry, recreation, and commercial buildings each account for an additional 4-7% of the catchment's area. Some roofs and foundation drains are connected to the sanitary sewer system.

This catchment is serviced by a separate sewer network. The storm sewer system outfalls at Haywood Drive and drains via Schneider's Creek into the Grand River.

Automatic sampling and monitoring of the Schneider's Creek catchment is carried out where the pipes outfall at Hayward Avenue. The range, standard deviation, and mean concentrations in the spring of 1976 for nine parameters are shown in Table A-16.

TABLE A-14. CARLING ST. CATCHMENT

Base Flow Water Quality Data (12), mg/ℓ

Group	Na	K	Ca	Mg	NH_3	NO_3	NO_2	TK*	SP*	TP*	Cl	F	SO_3	Si	DS*	pH	No*
A_1*	35	6.3	80	13	.051	0.4	.013	1.50	0.10	0.10	57	.9	35	2.7	345	7.5	0
B*	48	7.6	74	15	.030	1.1	.016	1.06	0.38	0.58	77	.8	50	3.3	394	7.8	18
A_2*	58	7.8	85	14	.105	0.7	.204	2.14	1.59	3.05	67	.8	61	5.8	406	7.6	9

Sample period: November 18th-23rd, 1975, 3 hour intervals.

*Abbreviations:

		B	Baseflow	TK	Total Kjeldahl
A_1	Diluted baseflow	DS	Dissolved Solids	TP	Total Phosphorus
A_2	Enriched baseflow	SP	Soluble Phosphorus	No.	Number of Samples

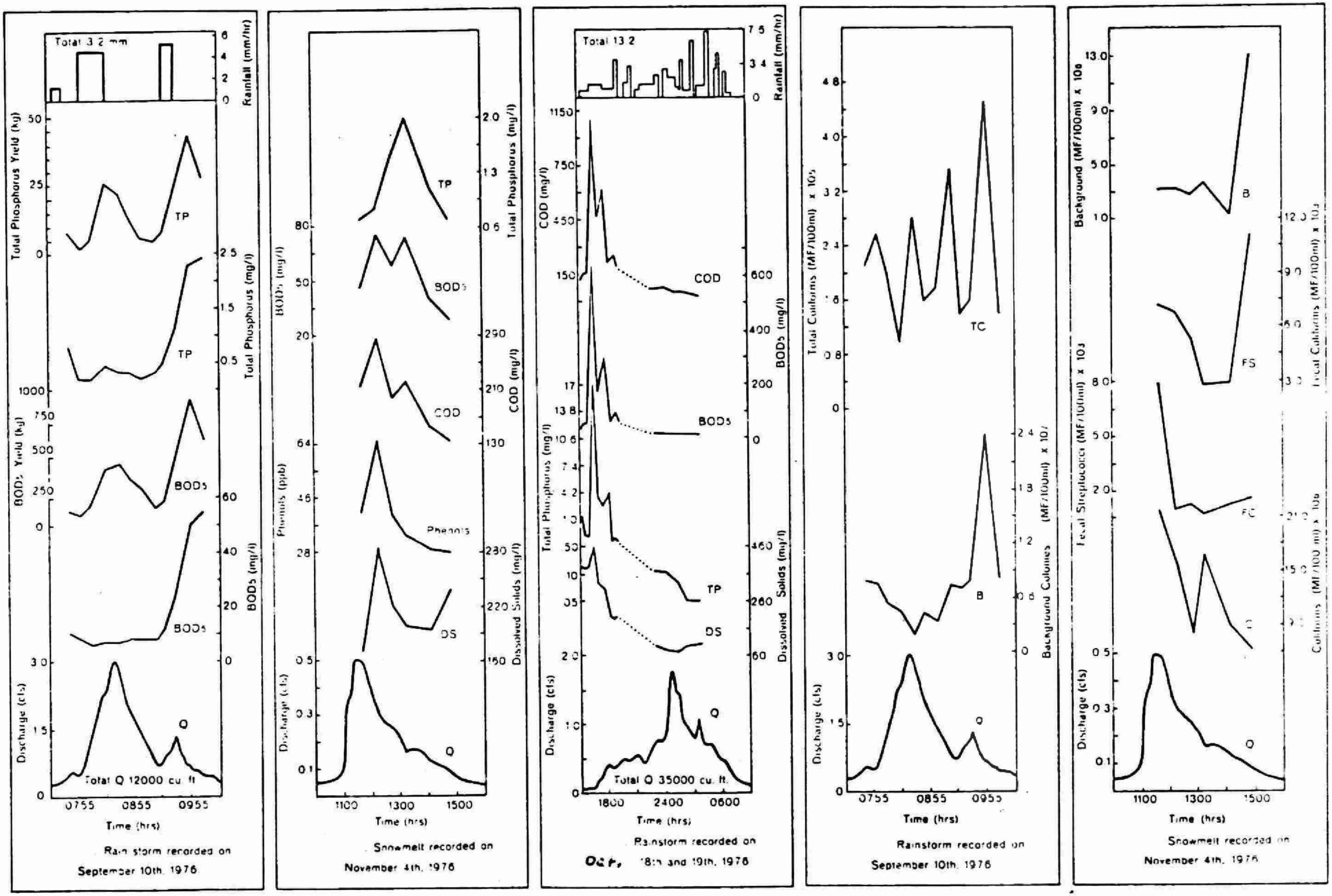


FIGURE A-1. CARLING ST. CATCHMENT - SELECTED WATER QUALITY PARAMETERS IN URBAN STORM WATER RUNOFF [12]

TABLE A-15. CARLING ST. CATCHMENT, LONDON, ONTARIO [12]

Observed Range, Mean Concentration, and Pollutant Loadings in Urban Storm Runoff

Date		Antecedent Period (days)	Total Flow (litres)	Duration of Runoff (hrs. min.)	BOD	COD	SS	DS	Total P	Diss. P.	Phenolic Comp.	Background Colonies	Total Coliform (MNP)	Fecal Coliform
Sept.10 1976	Range (Min-Max) mg/l				6 55	- -	13 61	102 184	0.2 2.4	- -	- -	$2.1x10^6$ $2.4x10^7$	$1x10^5$ $4.6x10^5$	- -
	Weighted Average Concentrations mg/l	0	346,232	3:15	16.8	-	39.0	140.	0.76	-	-	$7.5x10^6$	$2.19x10^5$	-
	Loading kg/ha/lbs./acre				36.7 202	- -	130 713	18.4 101	1.7 9.3	- -	- -	- -	- -	- -
Oct.18, 19, 1976	Range (Min-Max) mg/l				5.6 630	21 1096	6 126	68 458	.05 16.5	<0.05 7.45	- -	- -	- -	- -
	Weighted Average Concentration mg/l	9	1,001,997	20:00	42.5	114.2	37.0	135.0	0.61	0.22	-	-	-	-
	Loading kg/ha/lbs./acre				382 2097	1022 5607	331 1817	1208 6628	5.46 30	1.97 11	- -	- -	- -	- -
Nov. 4, 1976 (a,b)	Range (Min-Max) mg/l				28 76	133 281	25 209	171 282	7 20	- -	28 64	$1.5x10^6$ $1.3x10^7$	$6.5x10^5$ $2.2x10^6$	$6.0x10^2$ $7.9x10^3$

a-snowmelt
b-mostly for a peak flow range

TABLE A-16. SCHNEIDER'S CREEK CATCHMENT [15]

Water Quality Data Summary, UL-23
(Jan. 1 - Apr. 29, 1976)

Parameter	Range (mg/l) Min	Max	Standard Deviation	Mean (mg/l)	No. of Samples
Total P	.028	.730	.1557	.185	34
Total Kjeldahl Nitrogen	.36	2.52	.5542	.982	34
Ammonia (unfiltered)	.014	.700	.1509	.197	34
Suspended Solids	5	890	184.7	149.1	34
$NO_3 + NO_2$	.78	3.25	.7026	2.095	33
Pb	.003	.92	.190	.130	27
Cu	.005	.27	.057	.044	27
Zn	.027	.61	.149	.148	27
Ni	.001	.026	.006	.007	22

Montgomery Creek Catchment

The second monitored site within Schneider's Creek watershed is the Montgomery Creek catchment which outfalls at Shally Drive. Montgomery Creek is a tributary of Schneider's Creek. This catchment is located in the eastern portion of Kitchener-Waterloo and is similar to the Schneider's Creek catchment. It has a surface area of 970 hectares (2400 acres) and with a population density of 16.6 persons/ha, contains approximately 16,000 inhabitants. Residential single family housing accounts for 64% of the catchment area. Commercial and recreational land use accounts for 12% and 13%, respectively, of the basin, while 4% is covered by forests and 6% is paved roads.. Although this catchment has been monitored as part of the PLUARG program the data is not yet available.

12. East York-Frankdale Catchment (Combined Drainage)

The East York-Frankdale catchment is located 6 kg (4 miles) to the northeast of downtown Toronto in the Borough of East York. It has a drainage area of 155 hectares (383 acres) and the population is estimated to be 14,600 which is 94 persons per ha. The ground has an even slope between the highest elevation of 133 m (436.5 ft) and the lowest of 118 m (388.5 ft).

The land use is almost 90% single family residential. Open space and institutions account for the rest of the area. Total gross imperviousness within the catchment is 49%.

A combined sewer system services this older area. The outfall pipe is 168 cm in diameter. Further downstream, the sanitary flow is intercepted (capacity 2.5 x dry weather flow) and the excess bypasses into the Don River.

All roofs and foundations are connected to the sewer system. Street cleaning is conducted on a weekly basis, weather permitting.

Sequential quality samples have been taken by an automatic sampler. Figure A-2 shows the schematic of the data acquisition system. This system, with some minor breakdowns, has performed satisfactorily. Table A-17 demonstrates seasonal concentration variations based on 29 monitored events (1976). Table A-18 shows weighted average concentrations of chosen winter, spring and summer storms. The variations in the

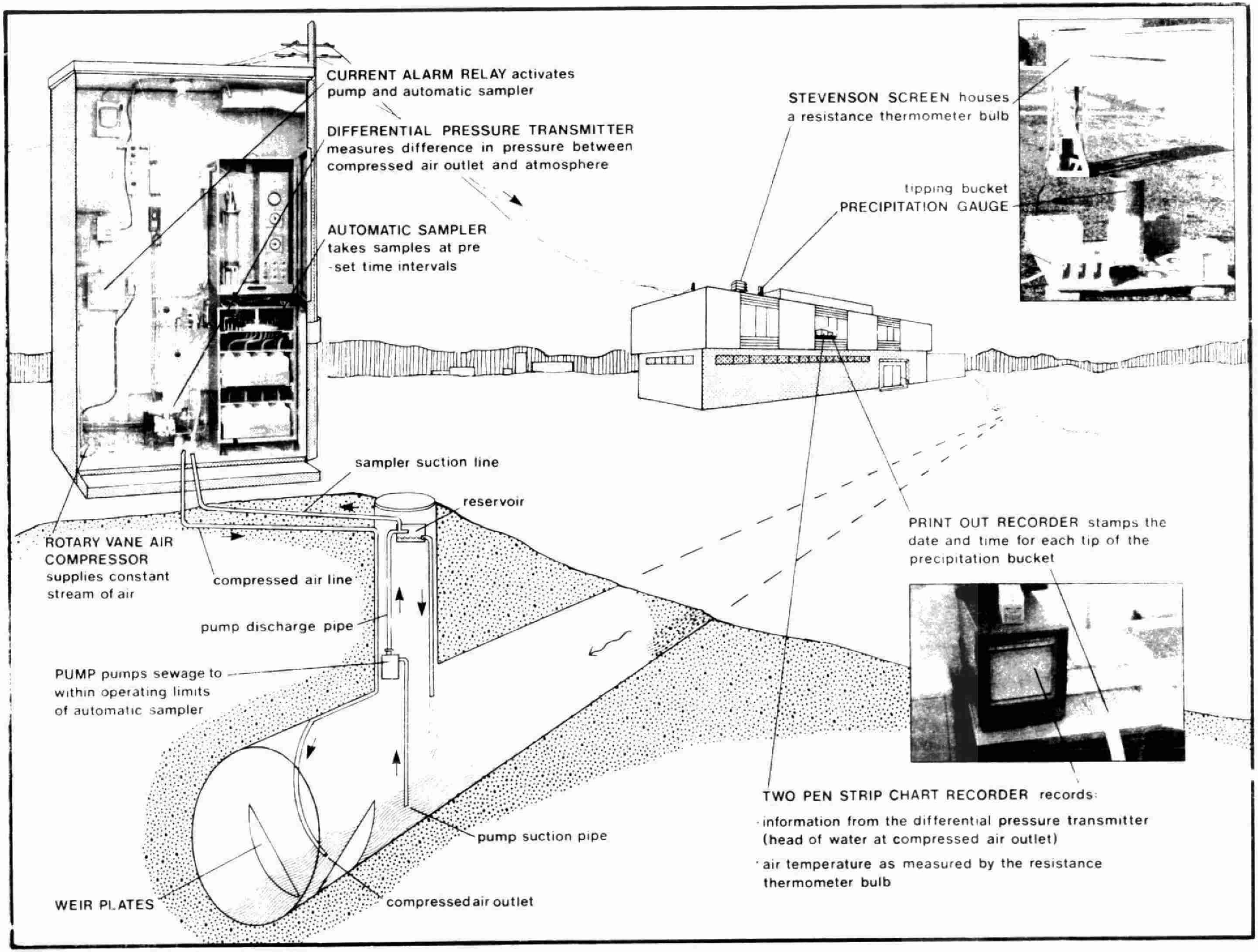


FIGURE A-2. SCHEMATIC OF DATA ACQUISITION SYSTEM - FRANKDALE CATCHMENT [22]

TABLE A-17. FRANKDALE CATCHMENT SEASONAL CONCENTRATION VARIATION [22]

(mg/l unless noted)

	WINTER	SPRING	SUMMER
BOD	13 - 150	4 - 280	8 - 180
COD	71 - 645	38 - 1090	35 - 755
CHLORIDE	141 - 3064	18 - 138	6 - 116
SULPHATE	21 - 84	11 - 35	7 - 31
CONDUCTIVITY	630 - 9000	180 - 680	84 - 385
LEAD	0.05 - 0.73	0.01 - 2.60	0.01 - 4.80
TOT. PHOSPHORUS	0.40 - 2.70	0.36 - 5.20	0.20 - 6.20
DISS. PHOSPHORUS	0.14 - 1.00	0.08 - 0.80	0.02 - 1.70
PHENOLS (PPB)	14 - 31	1 - 10	1 - 60
FREE AMMONIA	1.3 - 6.3	0.2 - 6.1	0.1 - 11
TOTAL KJELDAHL	3.2 - 13	2.6 - 26	1.8 - 25
NITRITE	0.02 - 0.70	0.01 - 0.38	0.01 - 0.53
NITRATE	0.2 - 2.0	0.1 - 2.8	0.1 - 2.4
SUSP. SOLIDS DRIED	60 - 560	32 - 2115	6 - 642
DISS. SOLIDS DRIED	320 - 4850	72 - 505	54 - 20,120
TOTAL SOLIDS DRIED	440 - 5070	150 - 2620	79 - 20,470

TABLE A-18. FRANKDALE CATCHMENT WEIGHTED AVERAGE CONCENTRATIONS OF THE WINTER, SPRING & SUMMER STORMS [22]*

Date	Mean Flow (cfs)	Duration (Hr:Min)	WEIGHTED AVERAGE CONCENTRATIONS (mg/l)						
			BOD	COD	Suspended Solids (Dried)	Phosphorus	Chloride	Lead	Total Kjeldahl
26/01/76	15.9	2:33	35	251	117	1.09	2510	0.37	8.6
27/03/76	18.7	1:26	58	365	412	2.24	88	1.09	11.1
29/07/76	26.7	1:20	45	175	111	1.71	26	0.79	7.2

*Portion of a runoff as monitored (i.e. portion of rising and falling limb not included).

quality of the baseflow will also be provided in the study. The monitoring of the runoff will be further extended to 1977 and the data collected from the test area will ultimately be used for the verification of the Storm Water Management Model (SWMM), Runoff and Transport blocks, and the Storage, Treatment, Overflow, Runoff Model (STORM).

13. Hamilton Catchment (Combined Drainage) [23]

The Hamilton catchment, located within the city limits of Hamilton, has a drainage area of 71 hectares (176.0 acres). The population in this catchment is approximately 3,050 (43 persons/hectare).

The predominant land use within the catchment is single family residential which accounts for 75% of the total area. Open space consumes 20% more of the catchment with the remaining 5% being used by institutions and commercial buildings. The total gross imperviousness is 36%. The street cleaning frequency is once a week on the major roads and once a month in residential districts.

The study area is serviced by a combined sewer system; 55 hectares of the catchment had combined sewers installed prior to 1950. During the early '60's the remaining area had separate sewers installed, which empty into the combined sewer system. Therefore, the whole catchment has the equivalent of a 100% combined sewer system. There are about 150 catch basins in total, equivalent to approximately 2 C.B./ha.

Of the total surface area, 8.1 hectares are sites under construction. This has caused the concentration of settleable solids to increase by a factor of about three in comparison to similar catchments.

Data collection for this catchment was initiated in later 1975, and is expected to continue into 1977. Flows are routed through a V-notch weir and the weir head is measured by a Bristol air-bubbler.

Water quality samples are collected sequentially at 5 to 10 minute intervals by a Sirco Automatic Sampler. The accompanying Table A-19 shows the range of concentrations for selected pollutants. The maximum values are instantaneous readings at peak flow.

During the storm of April 15, 1976 (antecedent period of 14 days) the concentration of total soluble solids reached a maximum of 2745 mg/l. This represents a loading of greater than 22.7 kg/minute (50 lb/min).

TABLE A-19. OBSERVED RANGE OF CONCENTRATIONS IN COMBINED WASTE RUNOFF - HAMILTON CATCHMENT [23]

October 1975 - September 1976 (17 Storms)

PARAMETER	Range of Concentrations mg/l MAXIMUM	MINIMUM
BOD_5	200	7.7
COD	2000	25.0
P	28	0.8
Total SS	2745	25.0
Fixed SS	740	4.0
VSS	1980	8.0
NH_3	31	0.8

There were storms in May, July, August and September of 1976 when concentrations stayed higher than 1500 mg/l for periods greater than 10 minutes. On July 16, and 19, the loading reached a maximum rate of 122 and 113.5 kg/minute (270 and 250 lb/minute) respectively. Out of 20 storms, COD reached a maximum loading of 32 kg/minute (70 lb/min). Two other events had loadings in excess of 23 kg/minute (50 lb/min) and another three in excess of 11 kg/minute (25 lb/minute).

14. <u>Aurora (Sanitary or Combined Bypass) [14]</u>

The Town of Aurora is located in the Holland-Schomberg River watershed which drains north to Lake Simcoe. The population in the catchment is 13,500. The catchment encompasses an area of 4,850 hectares (11,980 acres). Land use is 60% residential, 25% open land, 10% industrial, and 5% paved roads. Parts of the city are served by combined sewers and parts are served by separate sewers. Many roofs leaders and foundation drains are connected to the combined sewers (in unseparated areas) and the sanitary sewers (in separated areas). The quantity and quality of bypass was measured at the 76 cm diameter (30 in) outfall of the Aurora Water Pollution Control Plant (WPCP).

15. <u>Brantford (Sanitary Bypass) [14]</u>

The City of Brantford is in the Grand River basin. This 4,650 hectare (11,500 acre) urban drainage area has a population of 85,700. Land use is 44% single family residential, 25% open space, 18% industrial and the remaining 12% is commercial and institutional. Separate sewers are installed in this catchment but many roof leaders and foundation drains are connected to the sanitary sewer system. The quantity and quality of sanitary overflow is monitored at the 107 cm diameter (42 in) bypass pipe of the Brantford WPCP.

16. <u>Dundas (Untreated Wastes) (Sanitary Bypass)</u>

Dundas is situated west of Hamilton and northeast of Brantford at the base of the Niagara Escarpment. Although a separate sewer system has been installed, it is not connected properly, as some roof leaders and foundation drains are connected to the sanitary system. The quantity and quality of untreated discharge is monitored at the bypass pipe of the Dundas WPCP.

17. Waterloo (Sanitary Bypass) [14]

The City of Waterloo is situated in the Grand River basin. The catchment has an area of 6,632 hectares (16,400 acres) and a population of 45,000 persons. The land use is 57% open space, 27% single family residential, 10% industrial, 4% commercial, and 2% institutional. Total gross imperviousness is 22%. Waterloo is served by separate sewers with all catch basins connected to the storm sewer system. The roof drainage of older buildings is still connected to the sanitary system. The quantity and quality of sanitary sewage bypass was monitored at the Young Street pumping station and the Waterloo WPCP.

At Waterloo, Brantford, Aurora and Dundas, the objectives of water quality sampling were identical and equivalent systems were utilized. Sequential samples were taken by an automatic sampler which was activated by a float or conductivity switch. The data collected at these sites are summarized in the accompanying tables.

Tables A-20, A-21, and A-22 show the duration of bypass, volume of overflow, and the concentrations of major effluent constituents at Waterloo, Brantford, and Aurora, respectively, for a number of storm events. Table A-23 shows the summary of WPCP bypass activity; bypass mass discharge is estimated on an annual basis for 1974/75. Tables A-24 and A-25 show the precentage of pollutants and discharges that escape treatment through the bypass.

TABLE A-20. 1974 BYPASS SUMMARY [14]

WATERLOO WPCP

Date	Duration hrs	Total Flow IG	No. Samples Analyzed (1)	pH Range	BOD_5 ppm	Filt'd BOD_5 ppm	SS ppm	VSS ppm	KJ as ppm	NH_3 as ppm	Tot P ppm	Ortho P ppm	Cl^- ppm	DISCHARGE lbs BOD	DISCHARGE lbs SS	Nominal Cause of Bypass	
9/2/74	2.15	-	3	7.9/7.6	105	-	172	139	24	19	6.3	-	-	-	-		M
4/3/74	12.25	1×10^6e	1 (2)	7.3	87	-	330	116	12	3.6	2.4	-	-	870e	3,300e	R	-
4/4/74	6.00	6.0×10^5e	12	7.9/7.0	33	-	355	93	9	3	2.7	-	-	198e	2,130e	R	-
4-5/4/74	3.55	2.0×10^5e	7	7.9/7.2	88	-	199	106	-	12	4.6	-	-	176e	398e	R	-
9/4/74	2.42	2.4×10^5e	4	7.7/7.0	-	-	189	123	-	-	-	-	-	-	454e	R	-
16-17/5/74	36.00	2×10^7e	2 (3)	-	-	-	680	149	-	-	-	-	-	-	136,000e	R	M
14/7/74	3.30	2.21×10^5e	6	7.7/7.6	61	-	282	87	14	9.3	4.9	1.6	-	135	579e	R	-
15/7/74	1.38	7.0×10^4	3	8.3/7.5	78	-	163	105	28	18	5.3	1.6	-	55	114	R	-
20-21/11/74	13.42	5.3×10^5	23	9.5/4.8	85	61	264	113	22	11	3.6	0.9	378	451	1,339	R	-

WATERLOO PUMPING STATION

Date	Duration hrs	Total Flow IG	No. Samples Analyzed (1)	pH Range	BOD_5 ppm	Filt'd BOD_5 ppm	SS ppm	VSS ppm	KJ as ppm	NH_3 as ppm	Tot P ppm	Ortho P ppm	Cl^- ppm	DISCHARGE lbs BOD	DISCHARGE lbs SS	Nominal Cause	
4/3/74	3.50	2.0×10^5e	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
4/4/74	1.25	-	4	7.8/7.5	47	-	744	159	11	4	4.3	-	-	-	-	R	-
16-17/5/74	19.15	-	1	-	-	-	687	184	-	-	-	-	-	-	-	R	-

NOTE: - e - indicates an estimated quantity

R - Rainfall

M - Mechanical

(1) In some cases samples were composited to provide sufficient volume for analyses.

(2) 10-hr composite samples

(3) 12-hr composite samples

TABLE A-21. 1974 BYPASS SUMMARY [14]

BRANTFORD WPCP

Date	Duration (hrs)	Total Flow IG	No. Samples Analyzed (1)	pH Range	BOD_5 (ppm)	Filt'd BOD_5 (ppm)	SS (ppm)	VSS (ppm)	KJ as N (ppm)	NH_3 as N (ppm)	Tot P (ppm)	Ortho P (ppm)	Cl^- (ppm)	Discharge lbs BOD	Discharge lbs SS	Nominal Cause of Bypass	
27/1/74	2.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
4/4/74	1.75	-	3	7.3/7.0	77	-	305	182	12	4	3.4	-	-	-	-	R	-
16/5/74	1.75	1.3×10^5 e	1	7.1	46	-	646	479	24	-	6.6	-	-	-	-	R	-
21-22/5/74	14.30	4.7×10^6 e	26	7.3/7.2	52	-	166	133	16	-	3.4	-	-	2444 e	7802 e	R	M
22-23/5/74	19.30	3.0×10^6 e	14	-	92	-	161	145	-	-	4.2	-	-	2760 e	4830 e	R	M
23-24/5/74	18.30	3.0×10^6 e	24	-	85	-	167	147	-	-	3.9	-	-	2550 e	5010 e	R	M
24/5/74	12.10	8.9×10^5 e	18	7.5/7.2	73	-	182	144	15	4.7	3.9	-	-	650 e	1620 e	R	M
27/5/74	7.80	6.45×10^5	8	7.6/7.2	173	27	320	256	21	7.9	7.0	-	-	1116	2064	R	M
28/5/74	9.30	3.60×10^5	4 (2)	7.7/7.5	112	41	181	143	17	9.0	4.7	-	-	403	652	R	M
29/5/74	1.75	1.30×10^4	-	-	-	-	-	-	-	-	-	-	-			R	M
21/6/74	3.20	4.85×10^5	3	7.4/6.9	303	-	857	416	24	8.1	6.3	-	-	1470	4157	R	-
20/11/75	3.45	3.1×10^5 e	10	7.6/7.1	186	151	494	231	22	13.4	7.6	4.6	112	577 e	1531 e	R	-

NOTE: e - indicates an estimated quantity

R - Rainfall

M - Mechanical

(1) In some cases samples were composited to provide sufficient volume for analyses.

(2) 24-hr composite samples

TABLE A-22. 1974 BYPASS SUMMARY [14]

AURORA WPCP

Date	Duration hrs	Total Flow IG	No.(1) Samples Analyzed	pH Range	BOD_5 ppm	Filt'd BOD_5 ppm	SS ppm	VSS ppm	KJ as N ppm	NH_3 as N ppm	Tot P ppm	Ortho P ppm	Cl^- ppm	DISCHARGE lbs BOD	DISCHARGE lbs SS	Nominal Cause	
22/2/74	3.75	2.6×10^4e	6	9.9/7.8	135	-	546	223	21	11	2.7	-	-	35e	142e	R	-
4/3/74	3.08	8.3×10^4e	3	10.4/7.8	140	-	523	207	17	10.7	4.3	-	-	116e	434e	R	-
5/3/74	9.00	8.9×10^4e	10	8.7/7.6	64	-	201	-	18	9.6	3.7	-	-	57e	179e	R	-
7/3/74	11.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
30/3/74	1.05	-	1 (2)	8.0	49	-	358	185	28	21	5.0	-	-	-	-	R	-
2/4/74	2.65	-	1	-	41	-	390	193	-	-	5.0	-	-	-	-	R	-
5/4/74	2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
22/4/74	1.65	-	3 (2)	7.8/7.2	89	-	177	65	-	-	3.4	-	-	-	-	R	-
22/4/74	2.20	-	1	7.6	64	-	86	23	-	-	2.7	-	-	-	-	R	-
24/4/74	5.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
28/4/74	2.00	-	2	8.0/7.9	70	-	143	59	-	19	5.2	-	-	-	-	R	-
5/5/74	12.9	-	15	8.2/7.5	11	-	164	98	27	21	4.0	-	-	-	-	R	-
9/5/74	4.3	6.5×10^3	7	10.3/7.7	28	-	444	203	24	11.6	2.1	0.56	-	1.8	29	R	-
12/5/74	9.8	-	16	8.0/7.5	21	-	79	42	-	8.1	2.9	0.77	-	-	-	R	-
13/5/74	14.95	-	14	7.7/7.3	23	-	127	-	-	7.8	2.6	0.58	-	-	-	R	-
17/5/74	21.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
21/5/74	2.0	-	2	7.6/7.5	97	-	318	145	21	10.5	3.9	-	-	-	-	R	-
30/5/74	0.5	-	1	7.8	-	-	247	160	-	23	4.1	-	-	-	-	R	-
3/7/74	12.75	4.37×10^5	7	7.9/7.3	100	15	533	245	27	9.1	7.1	1.5	-	440	[illegible]	R	-
3/11/74	9.43	-	6	8.0/6.9	124	43	139	107	31	17.5	3.5	2.1	258	-	-	R	M
12/11/74	4.53	6.44×10^3	15	10.1/8.1	237	100	320	170	40	21	4.8	0.67	332	15	21	R	-
20/11/74	2.75	3.7×10^4	6	9.7/7.7	116	32	477	203	28	16.6	4.6	1.4	308	43	175	R	-
20-21/11/74	5.25	7.2×10^4	5	7.6/7.4	110	22	487	195	24	16.4	3.6	0.3	302	79	351	R	-
21/11/74	4.50	1.57×10^4	11	9.3/7.2	99	37	223	134	26	18.1	2.8	0.32	487	16	35	R	-

NOTE: - e - Indicates an estimated quantity

R - Rainfall

M - Mechanical

(1) In some cases samples were composited to provide sufficient volume for analyses

(2) 2-hr composite sample

TABLE A-23. SUMMARY OF W.P.C.P. BYPASS ACTIVITY FOR A TWELVE MONTH STUDY PERIOD BETWEEN JUNE 1974 AND JULY 1975

Municipality	Total Influent Volume to W.P.C.P. (IMG)	Total Volume Bypassed (IMG)	Total Time Under Bypass (hours)	Bypass Mass Discharge (lbs)			
				BOD	S.S.	Tot P	Kj/N
Aurora [1]	594.6	10.3	513.8	7,700	20,100	270	1,800
Brantford [2]	3920.6	17.1	71.4	17,000	39,600	740	2,900
Waterloo [3]	2258.9	10.2	53.9	10,400	19,400	287	340
Dundas [4]	695.5	0.12	120.6	81	170	3	18

[1]) Bypassed - Volume represents 97% of hours under bypass
- Loading represents 34% of the bypassed volume

[2]) Bypassed - Volume represents 100% of the hours under bypass
- Loading represents 100% of the bypassed volume

[3]) Bypassed - Volume represents 100% of the hours under bypass
- Loading represents 79% of the bypassed volume

[4]) Bypassed - Volume represents 34% of the hours under bypass
- Loading represents 34% of the bypassed volume.

TABLE A-24. BYPASS SUMMARY COMPARISON OF FLOWS AND LOADINGS [14]

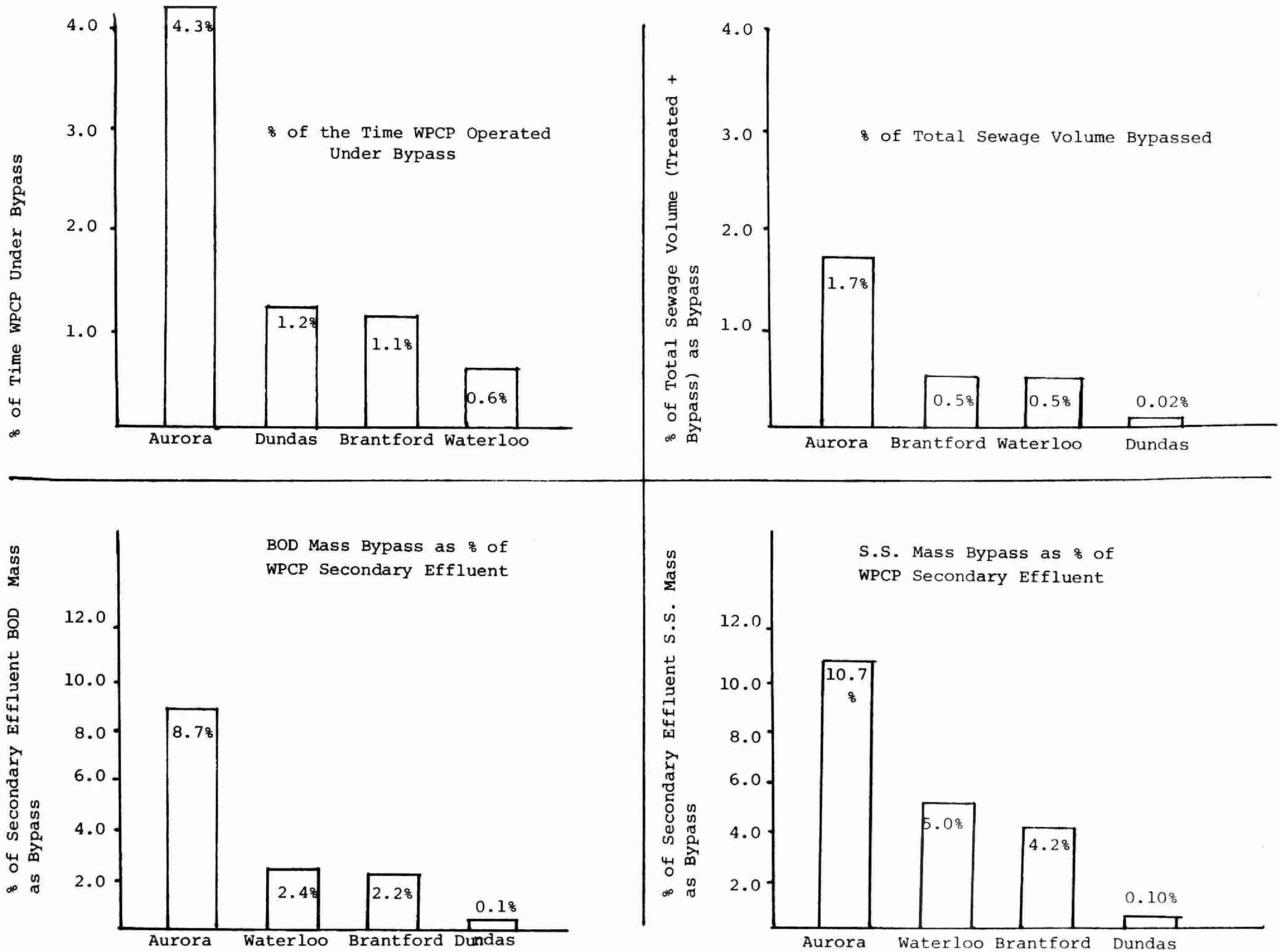
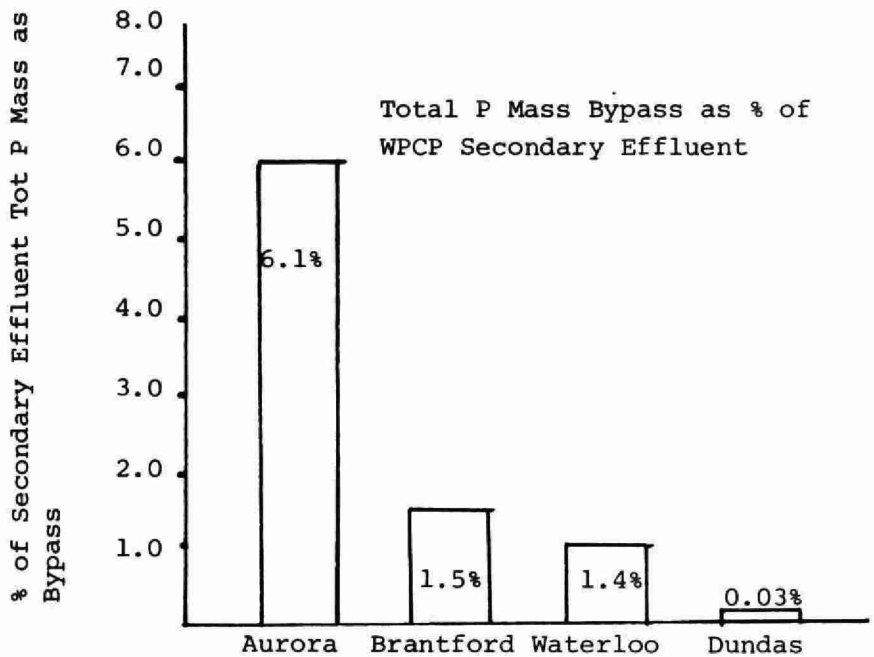
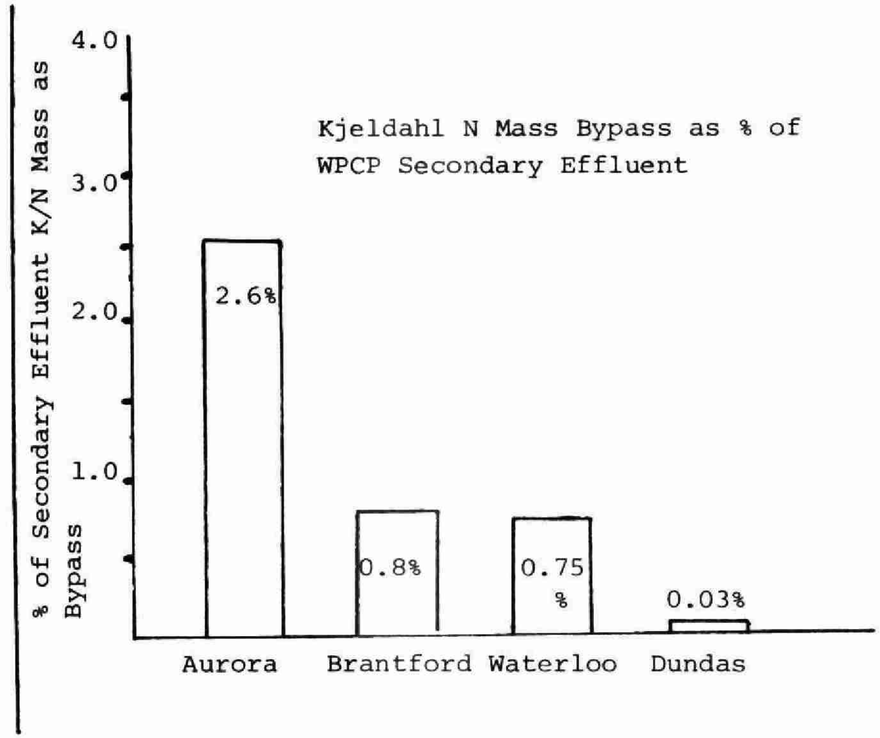


TABLE A-25. BYPASS SUMMARY COMPARISON OF LOADINGS [14]





HYDROLOGICAL ASPECTS OF URBAN DRAINAGE

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INTRODUCTION

The purpose of this paper is to bring to the attention of those who are involved in the design of urban storm drainage facilities the fact that a tremendous gap exists between the state-of-the-art in urban hydrology and the design procedures practised today. Surveys carried out in Canada show that much of the urban storm drainage design work is lacking in depth. This obvious lack of urban drainage understanding could result in unnecessary spending on storm sewer systems, or in many instances could fail to provide adequate protection. The question of protection and safety are important aspects in any project, but unfortunately, no safety factor can be applied in urban drainage design, until we are able to predict or control our weather. Some of the flooding problems related to urban drainage are not more than the minor nuisance type, while at the other extreme, flooding can cause possible loss of life.

The precipitation that falls on a watershed will run off in the direction of natural slopes. Along the way, some of it is lost in evapotranspiration, infiltration, and detention in natural and artificial depressions, with the remainder of the rainfall reaching the receiving stream as runoff. These basic processes of the hydrologic cycle are common to urban and rural watersheds. The only difference is that in urban watersheds, which are usually smaller, these processes are influenced by man.

During the infancy of hydrology in the early 1900's, the methods of estimating peak runoff from rural areas were based on judgement factors and usually one or two basin parameters such as drainage area were used in empirical formulae. With the increasing quantity and quality of data collected over the past decades, refinements have been made in the art of predicting peak runoff. This has led to the establishment of scientific methods in estimating and synthesizing hydrographs, or more recently in simulating the rainfall runoff process by computer models.

DUAL DRAINAGE CONCEPT

The aim of urban storm water management is to intercept, collect, transport and dispose of storm runoff. In the past, these functions were encouraged to be carried out as quickly as possible. Increased rates and volumes of runoff from urban development made this quick transfer of the water to the receiving stream more and more prone to intensify the problems of donwstream flooding, erosion, and sedimentation.

In the planning and design of urban runoff systems, consideration should be given to a wide range of storm conditions, ranging from the regularly expected storms such as the one in two years event to the major flood-producing storm such as the 1 in 100 years event. The installation of a minor drainage system should eliminate the inconvenience created by the more frequently occurring storms. The objective of modern urban planning is also to eliminate the major damage and possible loss of life created by designing a drainage system capable of handling the major storms. In ideal situations the two systems complement each other, resulting in reduced costs.

The convenience or minor drainage system designed to take the more frequent floods is made up of curbs, gutters, inlets, pipes or other conduits, swales, channels, and other facilities designed to minimize nuisance, inconvenience and hazards to persons and property.

The major drainage system made up of large conduits or open channels can create the majority of flooding problems in older urban areas due to undersized carrying capacity.

Design Frequency

The design frequency for the minor system is generally between two and ten years; however, the most common values adopted by municipalities are the two and five-year storms. With the introduction of a dual drainage system, the lower values can be justified in most instances.

The selection of the design criteria for the major system should take into consideration the question of possible loss of life, damage to existing or proposed development, and the effect of flooding on the environment.

The design flood can be selected from observed local data or in the absence of such, a storm frequency can be selected. Falling under the former category are the two most severe storms recorded in Ontario. They are Hurricane Hazel which occurred in 1954 in Southern Ontario and the storm observed in Timmins in 1961. Although these storms produced 7 to 8 inches of rainfall over a 12-hour period, the highest hourly intensity values never exceeded 2.08 inches per hour. This value can be compared with typical hourly rainfall intensities in Ontario for the following selected return periods:

25 year	2.07 inch/hour
50 year	2.33 inch/hour
100 year	2.66 inch/hour

Before the selection of design criteria, consideration should be given to the inherent risk factor. The three components which are closely linked together in the process of design criteria selection are:

1. design life of the project (usually 50 years);
2. design return period, and
3. risk of selected design flood being equalled or exceeded.

Figure 1 illustrates the relationship among the three components.

As expected, the lower the design flood, the greater the risk of the flood being exceeded over the selected design life. Generally, the design flood for the major drainage system is selected to have a return period of between 25 to 100 years.

The return period of a storm does not necessarily equal the return period of the flood peak caused by the same storm. This is mainly due to the influence of climatic conditions. Large storms after a long dry summer period will produce relatively little runoff, while a small storm on frozen ground will produce relatively high runoff.

Studies in the U.K.* derived the following relationship between the probabilities of storms and floods.

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* Flood Studies Report, Natural Environment Research Council, 1975.

RELATIONSHIP BETWEEN RETURN PERIOD AND RISK FOR SELECTED YEARS

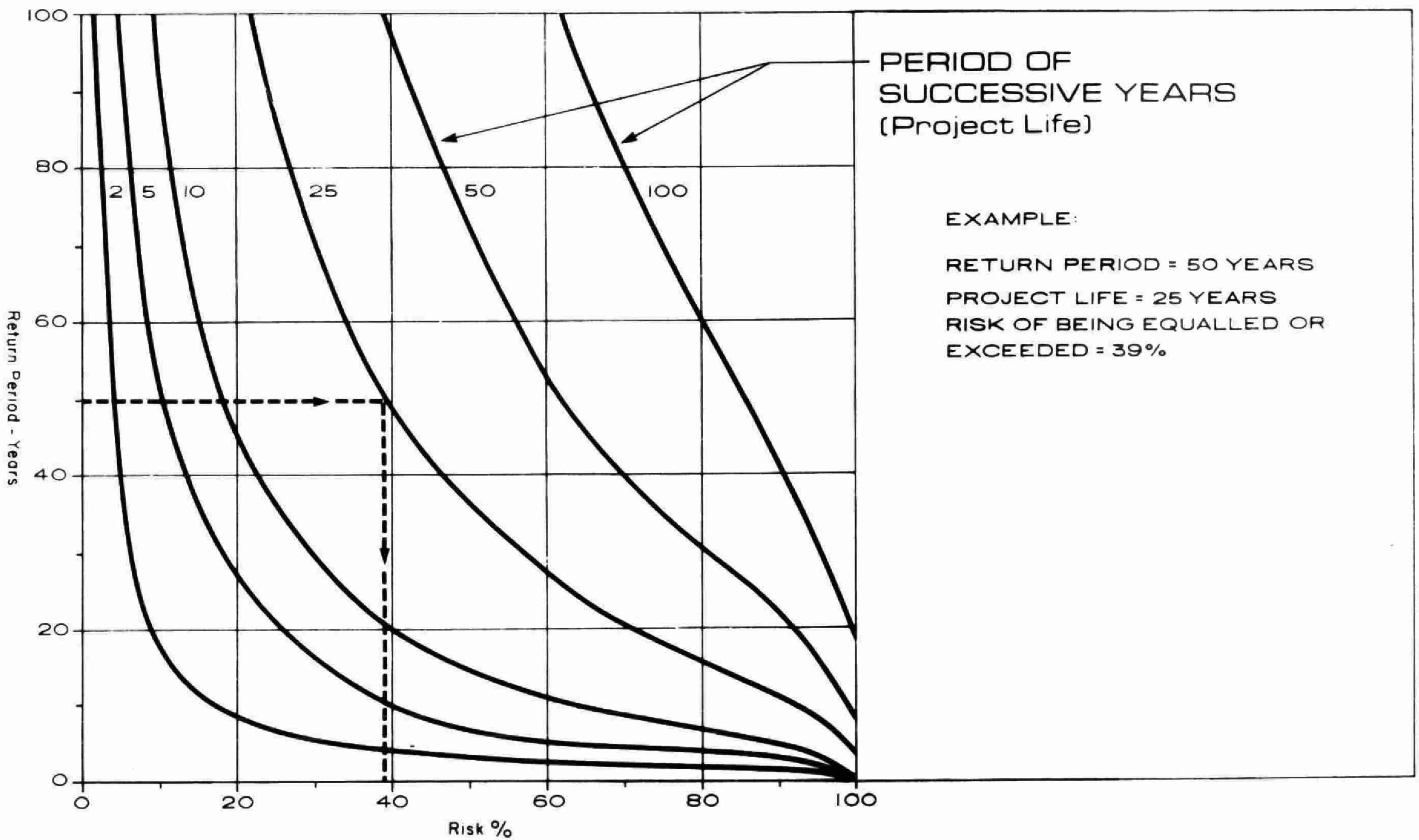

Fig.1

TABLE 1. STORM AND FLOOD PROBABILITIES

Storm Probability	Flood Peak Probability
5 Year	3 Year
10 Year	6 Year
25 Year	14 Year
35 Year	20 Year
50 Year	30 Year
75 Year	50 Year
100 Year	70 Year
250 Year	220 Year
500 Year	500 Year
1000 Year	1000 Year

RAINFALL

Most methods of designing urban drainage facilities require rainfall data as a major input. High intensity rainfall data is specified by three variables: frequency, duration, and either depth or mean intensity.

In general, the rainfall associated with the extreme floods of large streams is of relatively long duration, while the rainfall associated with the floods in a minor system is of shorter duration, usually less than two hours. As stream sizes decrease, their chances of being adequately gauged also decrease; therefore, short duration rainfalls of less than two hours are essential in flood estimation. Unfortunately, short duration rainfall data is deficient in many parts of the world because its proper collection requires continuously recording precipitation gauges.

High intensity rainfall frequency data is not usually accurate. Rainfall maps have standard errors of at least 10% for short return periods and 20% or more for return periods of 50 or 100 years. However, the estimates from the records at the basic rainfall stations are also subject to large errors, due mainly to sampling deficiencies, especially for long return periods.

The 68% confidence limits when estimating rainfall return periods using 25 years of records are as follows.

Estimated Return Period	Confidence Limit Upper	Confidence Limit Lower
50 Year	220 Year	12 Year
100 Year	400 Year	15 Year

As most of our rainfall recording stations have less than 25 years of data the confidence limits could be much wider.

In the analysis of urban drainage, the main concern is with rainfalls having relatively short durations. The extreme value of most of these rainfalls is associated with local convective rainfall cells which have similar physical properties. Research carried out in other countries showed that it is not unreasonable to expect consistencies in the data that will permit a high degree of generalization for estimation purposes.

In order to establish whether such a relationship exists between rainfall depth, duration and frequency in Ontario, a study of rainfall data recorded at 12 rainfall stations was carried out. This entailed obtaining the rainfall data for the selected stations from the Atmospheric Environment Service, Fisheries and Environment Canada, and then calculating depth-duration-frequency ratios for each station with the two-year one-hour duration as the denominator. The results of the computations are summarized in Table 2. Although the analysis is valid for short duration storms of up to two to three hours duration only, values for 6 and 24 hours are also computed and presented for guidance.

A detailed list of rainfall values for the two-year one-hour storm is given in the Appendix. Figure 2 should be used for locations not listed in the Appendix. Using the Toronto Bloor Street station as an example, the two-year one-hour value of 0.99 inches was used to compute the rainfall values using the values given in Table 2. The estimated values are compared with the data based on observation in Table 3.

The distribution of rainfall can have a marked effect on the runoff hydrograph. In order to establish a rainfall pattern for Ontario storms, 43 one-hour rainfalls were investigated to locate the maximum

TABLE 2. GENERALIZED RAINFALL VALUES

This table shows the MEAN VALUES for different return periods expressed as ratios of the two-year one-hour values.

Period	Duration							
	Minutes				Hours			
In years	5	10	15	30	1	2	6	24
2	0.37	0.54	0.62	0.79	1.00	1.22	1.59	2.14
5	0.52	0.73	0.85	1.13	1.43	1.71	2.17	2.93
10	0.61	0.86	1.01	1.37	1.71	2.01	2.55	3.46
25	0.73	1.03	1.21	1.65	2.07	2.41	3.04	4.13
50	0.82	1.15	1.36	1.86	2.33	2.71	3.47	4.62
100	0.92	1.28	1.51	2.06	2.60	3.00	3.76	5.11

TABLE 3. RAINFALL VALUES IN INCHES FOR TORONTO

Based on observed data and estimated values based on generalized relationship.

		Minutes				Hours	
Method of Calculations	Frequency	5	10	15	30	1	2
Observed	2 Year	0.37	0.51	0.62	0.80	0.99	1.18
Estimated	2 Year	0.37	0.54	0.62	0.79	0.99	1.22
Observed	5 Year	0.54	0.70	0.86	1.13	1.35	1.59
Estimated	5 Year	0.52	0.73	0.85	1.13	1.43	1.71
Observed	10 Year	0.65	0.83	1.02	1.35	1.59	1.86
Estimated	10 Year	0.61	0.86	1.01	1.37	1.31	2.01

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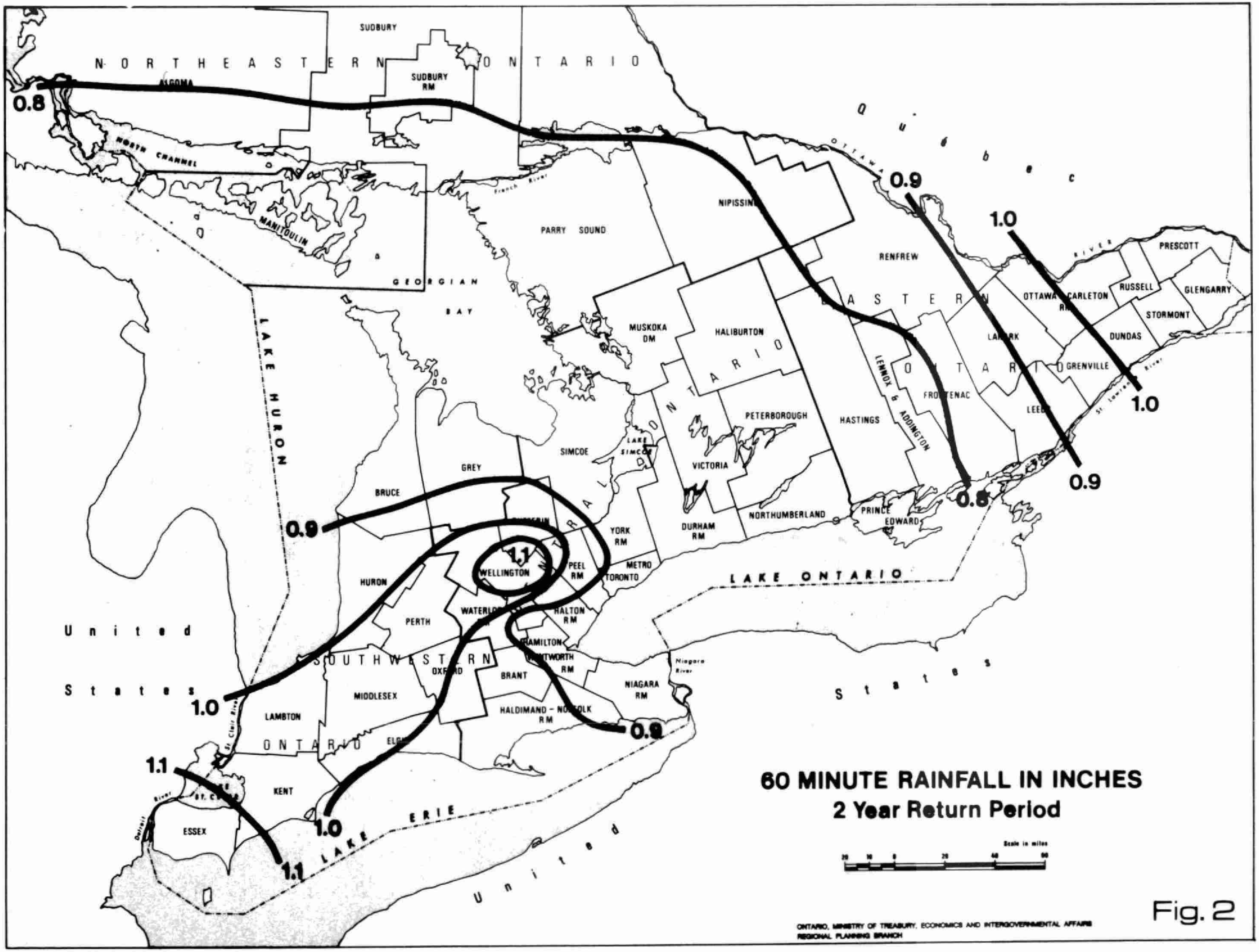

60 MINUTE RAINFALL IN INCHES
2 Year Return Period

Fig. 2

five-minute intensity. It was found that rainfall peaks can occur in any of the 12 five-minute intervals. The results of the calculations are plotted on Figure 3. For example, 50% of the storms analyzed had a peak within the first 42% of the storm duration (25 minutes), while the other 50% peaked during the last 35 minutes.

DESIGN METHODS

The most common methods used for urban hydrologic analysis can be classified into four categories:

1. Empirical formulae such as the Rational method.
2. Unit hydrograph techniques.
3. Computer models.
4. Analysis of existing gauged data.

Rational Method

The Rational method has been the predominant approach used for sizing storm sewers since Kuichling published his paper in 1889. He concluded his paper by stating, "investigations moreover show that larger quantities of storm water run off from urban surfaces than is commonly supposed and hence it is obvious that a more rational method of sewer computation is urgently demanded. Much room for improvement in this direction is still left and it is sincerely hoped that the efforts of the writer will be amply supplemented by many valuable suggestions and experimental data." He rejected the empirical conduit sizing method employed by his contemporaries and suggested that recognition should be given to the variability of rainfall so the storm sewers could be sized more realistically and reliably. He said in his paper, "it is not urgently advised to make use of a large number of automatic rain gauges scattered about in the various separate drainage basins and located not more than about 1,500 feet apart".

Kuichling also realized the significance of antecedent soil moisture condition in application of his findings, but this was ignored by the users. The numerous studies that followed concentrated on intensity-duration-frequency curves and runoff coefficients. Unfortunately, his recommendation on further development has not truly been met even to this day.

LOCATION OF PEAK INTENSITY
43 ONTARIO STORMS

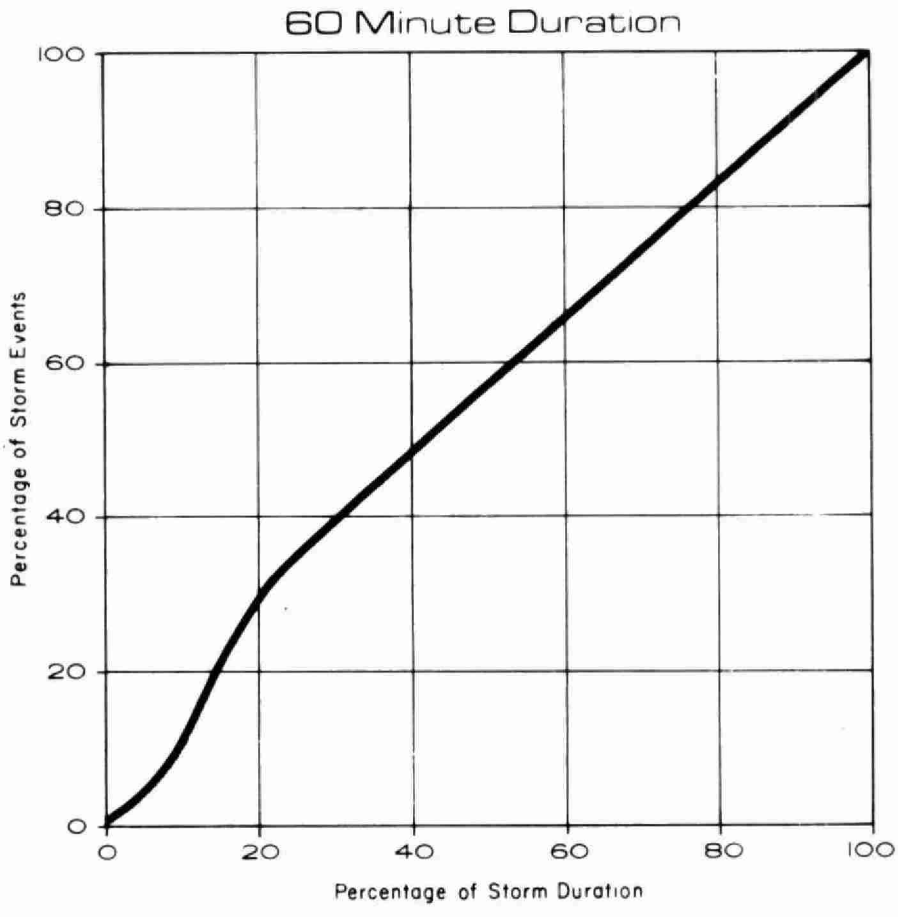

Fig. 3

Three factors affect the magnitude of a design flow for a given area in using the Rational method, Q = C x I x A,

1. the "C" value,
2. inlet time, and
3. the intensity "I" of the rainfall-frequency-duration curve used.

Calculated flows become larger as the C value is raised, as the inlet time is shortened and as a curve for a rarer rainfall frequency is used. A careful or in some cases fortunate selection of values for these three variables has been found to give satisfactory results in a number of cities. This is probably due to the fact that the probability of all design assumptions being satisfied simultaneously is less than the probability of occurrence of the rainfall rate used in the design.

A review of runoff coefficient values used in Canada indicate that these are selected on a variety of bases with no apparent coordination between sewer design of various cities. There appears to be very little research involved in current design practice in selecting the runoff coefficient.

The Rational method can be verified only when a recorded rainfall occurs in the field which has the same average rainfall over the time of concentration as was used in the design. Therefore, there is no other reliable way to compare a design flow calculated by the Rational method with a gauged flow, unless the rainfall has the proper intensity at the proper duration and occurs at a time in coincidence with the peak of recorded flow.

For a given drainage area size and C value, the Rational method peak flow is directly proportional to the design rainfall intensity. Assuming a ± 20% variability is permitted in the Rational method and this variability is attributed to rainfall intensity, it may be seen on Figure 4 that a five-year frequency value could mean anywhere between about a two-year and a 10-year value. Such a wide range could make the engineering and economic assessment of protection from flooding an exercise in futility.

THE EFFECT OF 20% VARIABILITY IN RAINFALL INTENSITY

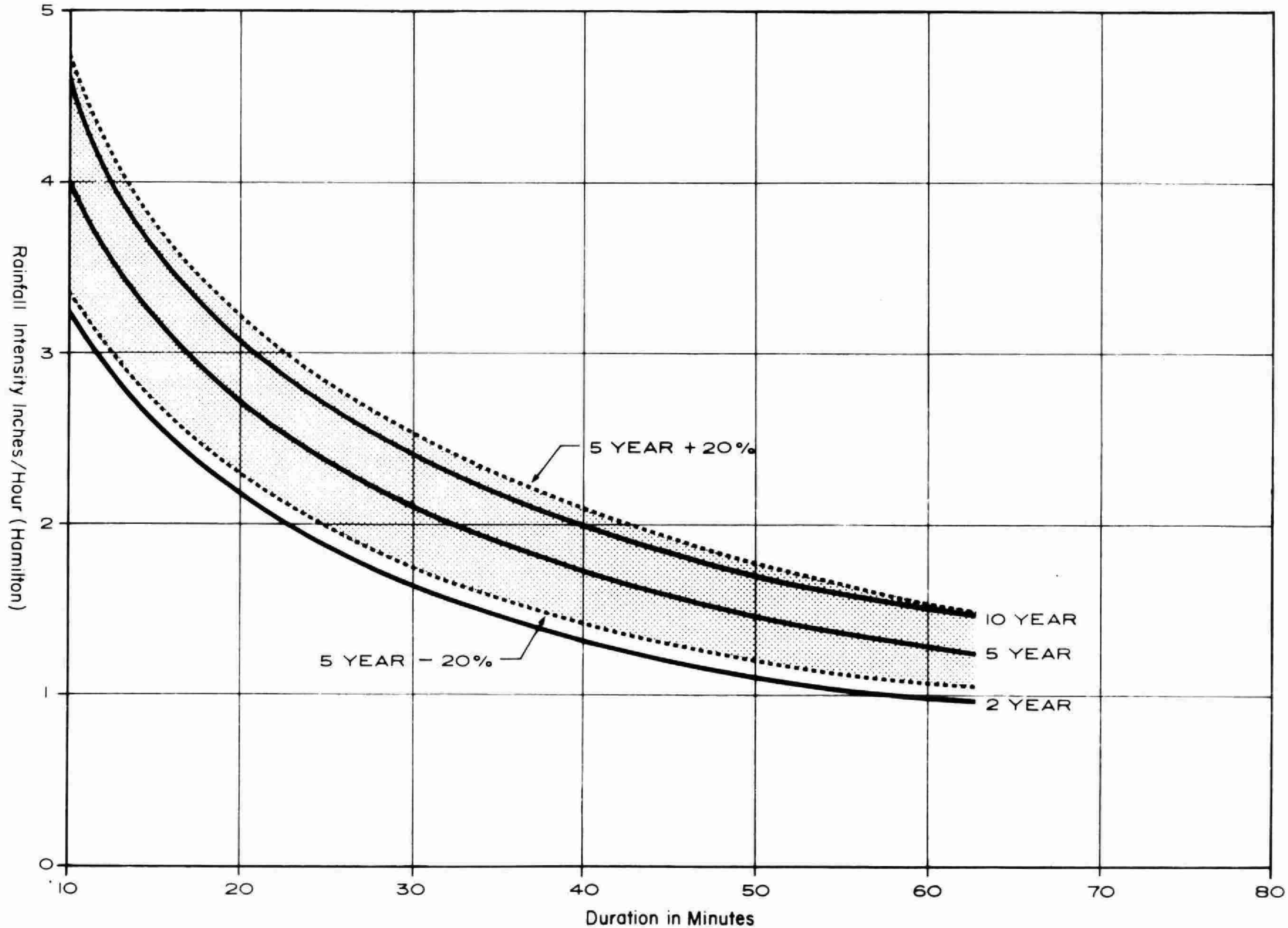

Fig. 4

It is evident that there are considerable variations in interpretation and methodology in the use of the Rational method. Because of its simplicity, it necessitates a wide range of subjective judgment in its application. If the emerging new design methods were not as promising as they are, it would be desirable that the ranges of interpretation of the Rational method be narrowed by formalizing Rational formula standards.

However, any new method for which there is any hope of replacing the Rational formula for design of urban storm drainage must be on the one hand more accurate in determining the complex relationship between rainfall and urban runoff, while on the other hand must be expressed in simple and clear terms that can be applied across Canada by the typical designer.

Unit Hydrograph

Since the early 1930's attempts have been made to develop alternative improved methods for flow predictions based on hydrologic parameters, but even the most promising methods have so far been usable only in the locality for which they were developed. The development of these improved design methods has been hindered for decades because of a lack of suitable field gauging rainfall-runoff program.

The most accurate hydrographs are prepared by actual gauges. Since such gauges are not usually available for urban drainage areas, some method for synthesizing hydrographs has to be considered.

The following data is needed to use the hydrograph method:

1. Basin characteristics
   Drainage area
   Length of main stream
   Slope of the main sewer
   Percent of impervious area

2. Climatological characteristics
   Storm rainfall hyetograph

3. Soil Characteristics and Land Use
   Regional coefficients

From a designer's point of view, the hydrograph method demands considerably more data, expertise, judgment and time than the Rational method.

In 1932 Sherman developed the unit hydrograph theory which became a universally accepted method of determining the flow hydrograph from rainfall. He postulated that the runoff hydrograph, due to a unit of effective rainfall spread uniformly in time over the entire area, in a unit period, was the tool to be used in runoff predictions. The basic assumption made in this theory is that a storm runoff derived from the effective rainfall by the use of unit hydrographs is based on a linear operation; that is, the composite hydrograph is obtained by adding the simultaneously occurring hydrograph estimates.

To synthesize a unit hydrograph, which can be used to derive a storm hydrograph, a set of coefficients has to be developed based on actual observed runoff data and on physical characteristics of the region.

According to Snyder there are two basic equations required to define the unit hydrograph peak:

$$t_p = C_t(L \times Lca)^{0.3}$$

$$q_p = \frac{640\ C_p}{t_p}$$

where:
- t_p = time to peak from mid point of unit rainfall, in hours,
- L = stream length from study point to upstream basin limit, in miles,
- L_{ca} = distance from study point along the stream to the centroid of the basin, in miles,
- q_p = peak rate of runoff in cfs/square mile,
- C_t = time peak coefficient,
- C_p = runoff peak coefficient.

Values for the coefficients and their relationship to the extent of urbanization, taken from two urban drainage studies, is shown in Table 4.

TABLE 4. UNIT HYDROGRAPH CO-EFFICIENTS

Impervious Area %	C_t Denver*	C_t U.K.**	C_p Denver	C_p U.K.
10	1.30	1.19	1.00	Constant 0.51
20	0.80	0.84	0.81	
30	0.55	0.69	0.68	
40	0.40	0.60	0.60	
60	0.30	0.49	0.52	
80	0.26	0.42	0.48	
100	0.25	0.38	0.47	

* Urban Storm Drainage Manual, Denver, Colorado.

** Black J., Synthetic Unit Hydrograph Produces in Urban Hydrology Proceeding, Nov. 1975, University of Kentucky.

The shape of the unit hydrograph can be drawn by determining the width at 50% and 75% of the peak discharge* or by following the dimensionless hydrograph shape suggested by the Soil Conservation Service**.

The popularity of the Soil Conservation Service triangular hydrograph method*** is due to the fact that it can predict complete hydrographs for rural and urban areas using manual or computer methods.

The original equation $Q = \frac{(P-0.2S)^2}{P+0.8S}$

developed for rural areas can be applied for urban areas by adjusting the potential abstraction parameter S, which consists of interception, infiltration and depression storage.

A comprehensive study**** of design methods used for flood peak calculation demonstrated that the peak flows estimated by the Rational method were on the average 2.01 times the recorded peak flows, while the 95% confidence limit ranged from 1.20 to 2.65 times the observed peak flow. On the other hand the Soil Conservation Service Unit Hydrograph method underpredicted the flows on the average by 0.64 times the recorded peak flow.

Computer Models

The proliferation of urban runoff models over the past decade produced a wide range of models, with differing sophistication, capabilities, limitations and costs.

As several excellent papers will be presented during the conference on this subject I would like to limit any comments to the following observations.

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* Urban Storm Drainage Manual, Denver, Colorado.

** Mockus, U., Use of Storm and Watershed Characteristics, U.S. Soil Conservation Service, 1957.

*** Urban Hydrology for Small Watersheds, U.S. Soil Conservation Service, January 1975.

**** Engineering Judgment and Small Area Flood Peaks, Hydrology Paper No. 19, Colorado State University.

1. Research in water resources and in particular in urban areas requires a vast array of good quantity and quality of data. This requires that about 80% of our efforts has to be spent on the difficult, expensive and dull task of data collection and preparation.

2. The new generation of computer methods can provide numerous volumes of printout, many down to 8 decimal places. However, we the practising engineers must ensure that with all these scientific wonders, we will not repeat yesterday's mistakes.

3. The "selling job" of convincing the practising engineer to use these modern methods will not be complete until it is demonstrated that the innovations are practical, useful, applicable, cost effective and meet the user's objective.

Flow Records

The use of available gauging records for urban drainage design is hampered by the scarcity of urban gauges and the effect of urbanization on runoff. Table 5 shows the effect of urban development on impervious area, ratio of rainfall - runoff and unit hydrograph peaks over a 15-year period for a drainage area of 297 square miles from data recorded in Germany*.

TABLE 5. EFFECT OF URBANIZATION

Years	Built up Area %	Impervious Area %	Runoff Rainfall Ratio	Unit Hydrograph Peak cfs/sq mi
1952 - 1957	36	9	13.7	68
1958 - 1962	40	11	17.6	86
1963 - 1967	44	13	19.0	95
1968 - 1972	48	15	19.6	105

* Wittenberg, H., A model to predict the effect of urbanization on watershed response, Nov. 1975, Proceedings, University of Kentucky.

EFFECTS OF URBANIZATION ON THE HYDROLOGY OR RUNOFF

Ideally the effect of urbanization on the watershed should be studied on long term stream flow records. Unfortunately, at present, there is a lack of long term gauging data recording runoff from small drainage areas. Therefore, most of the available data in the literature is based on computer modelling.

Generally, urbanization will affect the volume of runoff and the distribution of runoff in time. Urbanization will result in covering large areas of the soil with impervious material. However, urban areas are not completely covered by impervious structures and the soils are still important factors in estimating the total runoff. Urbanization on soils such as sands or gravel with high infiltration rates will increase the volume of runoff and the peak discharge more than urbanization on soils with low infiltration rates such as clays.

Investigations have shown that runoff from rainfall events less severe than the mean annual storm comes primarily from the impervious areas. This is demonstrated in Figure 5 which illustrates recorded total rainfall and runoff values in East York.

Urbanization can have a marked effect on the sediment yield in the receiving streams. Recent studies carried out on a 4.4 square mile watershed near Toronto showed, that during the period 1969 to 1975 when construction activities were at a peak, the sediment yield increased to approximately 370 tons per square mile per year from a pre-construction rate of approximately 50 tons per square mile per year.

The current state-of-the-art in the analysis of the impacts of urbanization on runoff has been advocating analysis of changes in the physical parameters of the catchment or in certain properties of runoff hydrographs. Available studies describing the effects of channelization and the effects of impervious surfaces are limited to general observations.

The Soil Conservation Service hydrograph method makes allowance for the increased runoff and reduced time of concentration due to urbanization. Table 6 shows the effect of urbanization on 2" total rainfall using the above method.

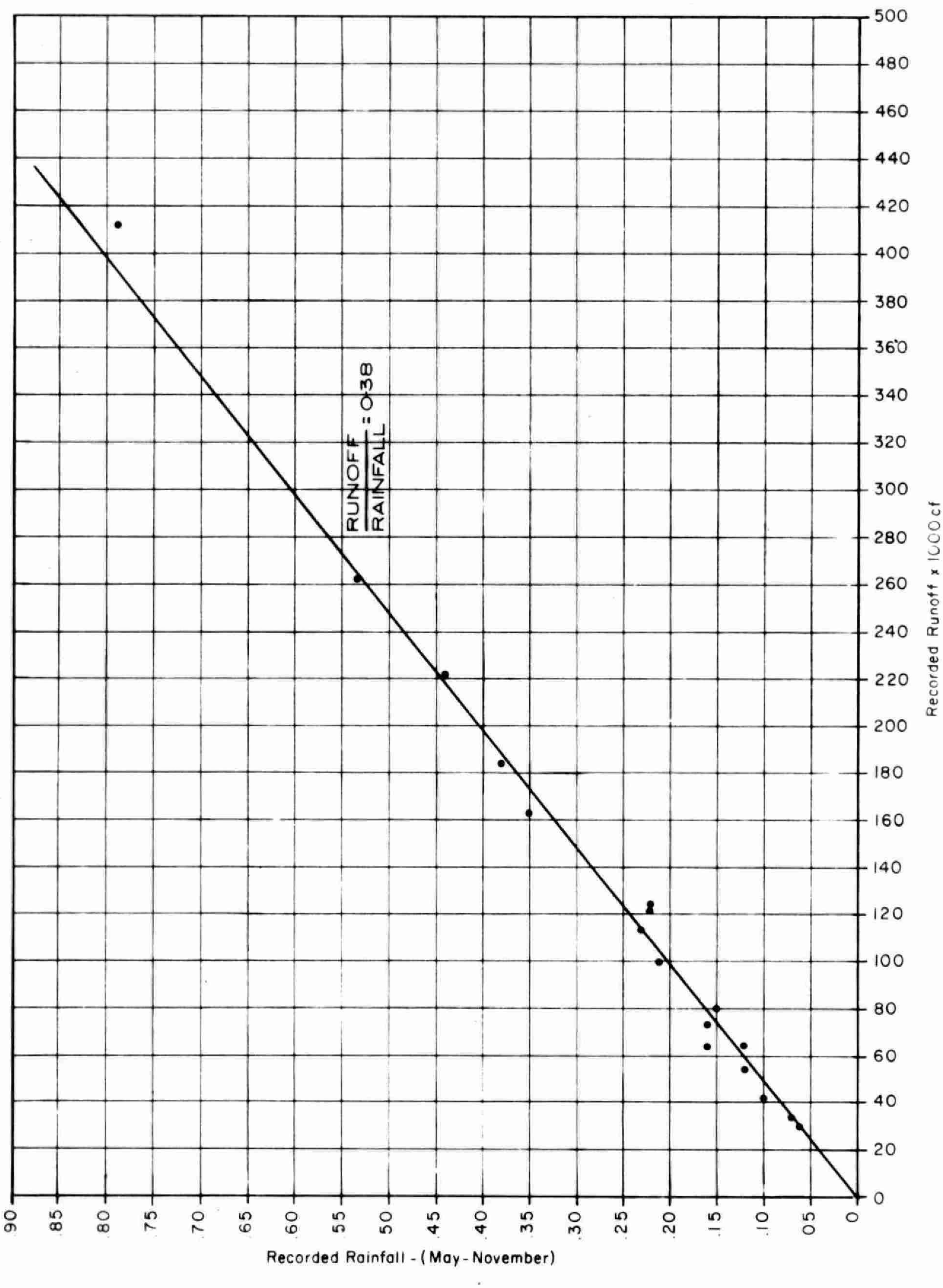


Fig. 5

RAINFALL-RUNOFF
Fully Urbanized Catchment in East York,
383 Acres, 49% Impervious

TABLE 6. EFFECT OF URBANIZATION
(Rainfall = 2.00 Inches)

	Impervious Area %			
	0	30	60	90
Runoff inches	0.06	0.30	0.65	1.40
Runoff %	3	15	31	70
Time lag factor	1.00	0.85	0.68	0.53
Peak flow factor	1.00	1.16	1.32	1.56

One of the few investigations on urbanization* which is based on recorded hydrographs concluded that unit hydrograph peaks and shapes can be correlated with watershed areas and extent of development. For example a change in population density from 100 to 13,000 persons/sq. mile will increase the peak hydrograph flow 10 times, while the time parameters are reduced about one-tenth.

CONCLUSIONS

The prediction of magnitude and frequency of discharges in conduits and open watercourses in rural or urban areas generated a wide variety of methods in the past 50 years. Unfortunately, most work carried out over the first 40 years dealt with either rural or urban discharge areas, which created two different branches of hydrology not to mention confusion among the practising engineers.

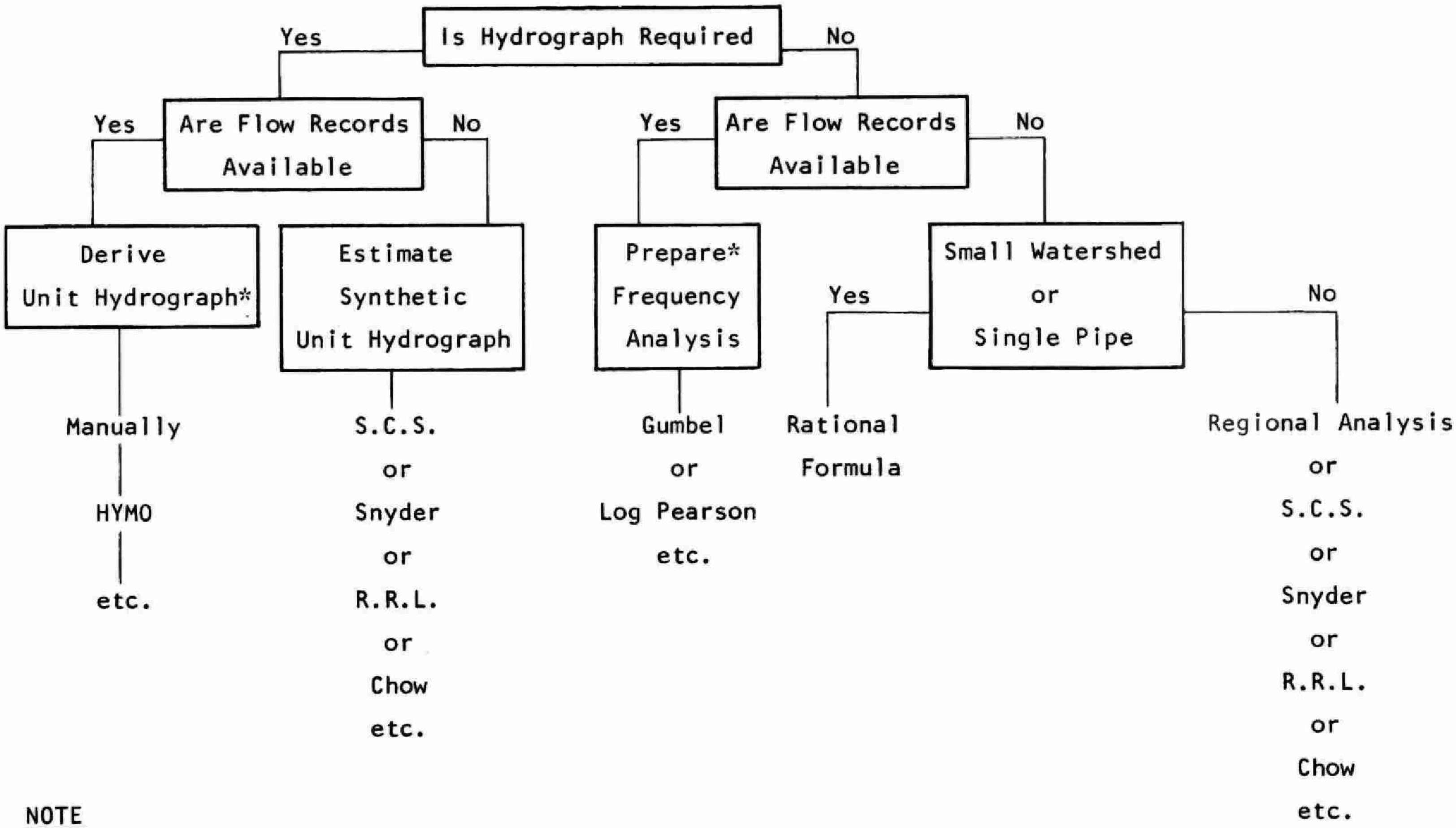
The failure to recognize the need for a method capable of combining the urban and rural hydrology is being remedied by the new computer methods. It is hoped that the wide gulf between the hydrologist and the practising engineer will be narrowed in the near future.

The following check list summarizes the hydrological procedures in calculating runoff:

1. Selection of design criteria
   (a) Ideally it should be based on economic analysis.
   (b) Minor system; 2 - 10 year.

* Brater, E.F., Rainfall-Runoff relation on urban and rural catchments, Michigan University, May 1975.

SELECTION OF DESIGN METHOD



NOTE

Computer models such as SWMM are not listed but could be used in all instances.

*Allow for effect of urbanization in the data analysis.

Fig. 6

(c) Major system; 50 - 100 year or Regional Storm.

2. Precipitation data
   (a) Analysis of local rain gauge data.
   (b) Generalized rainfall method.
3. Time of concentration
   (a) Calculate from recorded data.
   (b) Soil Conservation Service method.
4. Method of calculation
   A simplified chart to assist in the selection of different methods is presented on Figure 6.

APPENDIX

Rainfall Values in Ontario for Two-year One-hour Duration

Station	Rainfall
Abitibi	0.78
Appleby	0.77
Bark Lake Dam	0.83
Belleville	0.75
Brantford	0.89
Chalk River	0.81
Combermere	0.81
Delhi	0.87
Ear Falls	0.72
Fergus	1.15
Geraldton	0.69
Glen Allen	0.96
Greenwood	0.80
Guelph	0.96
Hamilton	0.84
Kitchener	0.91
Kingston	0.85
Lacave	0.79
London	1.00

Station	Rainfall
Mount Forest	0.96
North Bay	0.99
Ottawa	0.98
Prospect Hill	1.11
Port Colbourne	0.93
Ragged Rapids	0.96
Rayner	0.75
Ridgetown	1.04
St. Catharines	1.01
St. Thomas	0.99
Sault Ste. Marie	0.73
Simcoe	0.96
Sioux Lookout	0.90
Smith Falls	0.98
Sudbury	0.81
Thunder Bay	0.80
Timmins	0.70
Toronto	0.99
Toronto Malton	0.88
Tweed	0.74
Upper Notch	0.81
White River	0.77
Windsor	1.19
Woodstock	0.96

POLITICAL ASPECTS OF URBAN DRAINAGE

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City of St. Thomas, Ontario.

INTRODUCTION

Today's councils as never before, are faced with numerous issues requiring action to ensure the preservation and development of the well-being of the municipality.

Individuals, groups and other levels of government are requesting and demanding improvements and changes in all municipal systems. Not the least of these is in the area of sewerage.

Elected officials are exposed to and are expected to react to such popular terms as:

- zero runoff,
- storm water treatment,
- floodplain management,
- stream assimilative capacities.

These concepts, whether advocated by knowledgeable or unknowledgeable persons or groups, are directed to councils to be translated into policy and action.

In a society which expects instant solutions, it is imperative that municipal councils not react in haste but be given an opportunity to formulate policy based on such considerations as:

- sound engineering practise,
- benefit to cost analyses,
- planning and development policies of the municipality,
- ability to pay.

The political decision-making process will be viewed within this framework and, while considerable reference will be made to the situation within the City of St. Thomas, the principles should have general application.

HISTORICAL DEVELOPMENT OF THE ST. THOMAS SYSTEM

The City of St. Thomas, with a present population of some 27,000 people, lies approximately ten miles south of the City of London and nine miles north of the north shore of Lake Erie. The City is developed on table-land with topographic relief provided by a valley system, the largest being the Kettle Creek Valley which contains the receiving stream for the treated sewage from both the City and upstream users. Other secondary ravines project into the City and are used mainly for storm outlet purposes and as a route for the trunk sanitary sewer. The older commercial and residential portions of the city were initially developed with separate systems; however, councils of the day effected certain changes such that today these systems are predominantly combined. To quote from the Historical Development of the Drainage Systems of the City, compiled by a former City Engineer,

> "At the turn of the century Mr. James Bell warned the Council that a system of storm sewers should be installed and more especially to drain the street surfaces. He anticipated that the roof connections would be served by this proposed new system; however, he was not able to convince the Council of the period of the need for these new sewers. Aldermen reasoned that if there was a pipeline already in the street what was the harm in connecting the catch basins to it?"

For the past several years the newly sewered areas of the City have been developed with separate systems; however, a good part of the older downstream areas are still served by combined sewers.

SYSTEM CONDITION AND ADEQUACY

During periods of dry weather flow sanitary sewage is directed to the pollution control plant situated in the Creek Valley. During periods of rainfall the combined systems become overloaded and surcharging into areas with separate systems and overflows due to inter-connections occur. The effects vary depending on the magnitude of the storm; however, even moderate rainfalls result in some noticeable effects. Heavy storms invariably result in:

- basement flooding with attendant property damage,
- combined sewer overflows to receiving streams,
- overloading of pollution control plant.

The effects of these occurrences will be described in greater detail in other papers presented during this seminar.

Recognizing the need for action, the City Council responded some ten years ago by retaining a consulting firm to undertake a comprehensive sewerage and drainage study.* It recommended that storm relief sewers should be constructed with the ultimate objective of attaining total separation.

The separation program has partially been implemented consistently over the years and it is the City's present policy that sewer separation should be effected. Recognizing, however, that advances had been made in storm water management since the original study was undertaken, Council sought government assistance for a storm water management demonstration project.

POLITICAL CONSIDERATIONS

Within the framework of the decision-making process councils must have regard for the following:

- needs and demands of the residential, commercial and industrial sectors and special interest groups;
- requirements of the Provincial ministries (Ministry of the Environment, Ministry of Housing, Ministry of Natural Resources);
- possible growth limitations due to inadequate sewerage services;
- financial capability to fund sewerage and other capital programs.

Local Issues

The character of residential basements has changed through the years from use as storage areas to use as living space, usually well

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* Report on the Storm Relief and Development of Sewerage and Drainage Systems for the City of St. Thomas, James F. Maclaren Limited, December, 1968.

furnished and equipped. Sewer back-up can cause structural damage and usually results in damaged furnishings. The objectionable clean-up operations with the attendant health hazards inevitably result in collective citizen demands to council for immediate action.

In commercial premises flooding of basements creates the same problems as in the residential situation and the loss of goods is in some cases compounded by loss of area for retail purposes. This results in loss of revenue and devaluing of the rental potential.

Insurance for sewer back-up is available to residential property owners, although few if any have insurance since it is not commonly included in the standard household policy.

It is not, however, available to the commercial retailer on stock and equipment in even the broadest of available coverage. Losses are borne in total by the retailer.

During periods of basement flooding councils are often confronted by charges of improper sewerage systems and demands for recovery of costs due to losses. An example of political response was typified when in 1973 the Mayor of Ottawa referred to the Provincial/Municipal Liaison Committee the question of insurance provisions for persons suffering from sewer back-up and flooding. As a result the Municipal Liaison Committee requested the Province to consider:

a) the enactment of legislation that would require insurance companies to reintroduce, at a reasonable cost, optional coverage of these losses into homeowners' policies; or
b) the establishment of a Provincial/Municipal fund to assist people in need as a result of such flooding and back-ups.

This matter did take a different direction; however, the question of sewer back-up is still under active consideration by the Municipal Liaison Committee.

Provincial Concerns and Requirements

Sewerage policies are influenced by Provincial government legislation administered mainly through the Ministry of the Environment.

Concerns about sewer and pollution control plant capacity and the assimilative capacity of receiving streams to meet water quality objectives are often misunderstood by many councils. While councils may not totally comprehend the terminology they do understand the consequences of their failure to respond. For example:

1) In the late 1960's the Ontario Water Resources Commission imposed a freeze on development in the City of St. Thomas until agreement to participate in a Lake Erie regional water supply scheme was reached. Prior to this the City's water supply was obtained by surface impounding on Kettle Creek and from deep well sources. The commission argued that the use of surface water removed water from Kettle Creek thus reducing the Creek's assimilative capacity;

2) At present there is control on residential subdivison development. It would appear that the growth controls will be maintained until a comprehensive pollution abatement program is adopted and implemented.

Provincial Ministerial Philosophies

Compounding the decision-making process at the municipal council level are the varying policies and objectives of some Provincial ministries. In the "great environment parade" there is the belief held by some municipal councillors that some ministries are "marching to the beat of a different drummer".

The Ministry of Housing advocates more and lower housing costs -- attempting to achieve this objective by reduction of engineering standards and planning concepts.*

The Ministry of Natural Resources has effected land use control through floodplain and regional storm criteria -- the application of which in some municipalities has resulted in much higher than normal engineering standards being required, which has in turn frustrated subdivison development.

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* Urban Development Standards, Local Planning Branch, Ontario Ministry of Housing.

Growth Limitations - The Consequences

The spectre of growth control, whether imposed by the Province to achieve its objectives or by local interests, materially affects the economic position of any municipality. Most municipal councillors realize that notwithstanding government grants and loans the "money" required to realize objectives can only be met by an expanding assessment base.

In a like manner the industrial and commercial assessment base is threatened by growth control and collectively business and industry do not take lightly to the prospect of curtailing their operations or expansion plans. Their success is predicated on a healthy community able to supply the necessary housing and the supportive services required to maintain an adequate labour market.

Municipal Economics - Funding Capability and Management

Available municipal revenue other than from taxation comes from grants and subsidies. The revenue of a municipality is used to pay for the operating and maintenance expenses incurred annually and the debenture debt of capital works. Municipalities annually prepare a capital expenditure forecast for both the immediate year's program as well as a forecast for at least a five-year period. A capital expenditure forecast should also be based on guidelines established for the municipality relating to their debt carrying capability. How much is affordable and what are the yardsticks?

An examination of capital expenditure forecasts for municipalities would generally indicate that debenture debt is on the increase. In essence, expenditures will be exceeding revenue. The Ontario Municipal Board, which has the approving function for the incurring of debt by municipalities, has of recent years been maintaining tighter control on expenditures and on the types of programs proposed by municipalities. They are being very critical and, in some cases, are rejecting programs for anything but immediate needs. Faced with this municipal councils have found means for raising additional revenue using such practices as imposition of imposts* and sewer rates to help offset the cost of services.

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* Interim Report from AMO Special Committee on Municipal Cash Imposts.

Sewerage and, in particular, sewer separation programs are extremely costly. It has been estimated that the total cost required to separate combined systems in Ontario approximates $3.5 billion dollars. While this figure is not a refined calculation more recent examples in various municipalities do tend to support the high costs involved:

Sewer Separation Examples

a) City of St. Thomas

Total cost of major storm trunks. Laterals for combined sewer area of 950 acres estimated at $3,000-$4,000 per acre, not included above.	$ 4.2 million (1968 estimate, E.N.R. Index 1190)

b) Borough of York

Construction of outlet trunks and road storm sewers to separate 104 acres. Single family residential at a cost of $13,000.00 per acre. (Did not include other relief sewers or certain trunks funded by other authorities)	$1.35 million (1974 estimate)

c) City of Chatham

Storm sewers to separate combined sewer area in system whose combined sewers represent 35.65 miles in a system whose total mileage is 161.82.	$ 8.0 million (1974 estimate)

d) Medium-Sized Southern Ontario City

Total separation costs, including trunks and laterals but excluding road restoration and engineering and contingency costs in a drainage area of 250 acres.	$ 4.8 million (1976 estimate)

The total provincial budget commitment for capital construction programs for sewerage facilities which include treatment plants, trunk sewers and collectors in Ontario, was as follows:

YEAR	BUDGET COMMITMENT (millions of dollars)
1970	78
1971	98
1972	108
1973	217
1974	169
1975	173
1976	236

A study of the above figures would suggest that municipalities must find alternative sources of funding and, certainly, should welcome programs which might provide less costly and acceptable alternatives to the high cost of sewer separation.

Many municipal councils feel that imposts do provide this needed revenue yet the Ministry of Housing views imposts as being a deterrent to providing lower cost housing.

Some agreement or understanding regarding imposts should be reached if the common objective of providing adequate housing is to be attained.

Legal Considerations

The law and liability must be considered in any assessment process. Legal action is usually threatened by persons suffering damage or loss and actions of various kinds have been taken against municipalities.

The implementation, maintenance, operation and use of works carry with them certain obligations in law.

Riparian Rights - Riparian rights arise in respect of ownership of land which has actual frontage on a natural water-course.

Municipalities as land-owners have the same rights and obligations as other land-owners. Generally speaking,

a) A riparian owner has the proprietary right to have the water in the natural water-course flow to him in its natural state, neither increased nor diminished in quantity or quality. He is also entitled to use it for domestic or natural purposes. Failure to consider these rights can prove costly. For example, in Groat v. City of Edmonton*:

> "The city had constructed a large storm sewer having its outlet in an arm of a stream above the plantiff's land. The primary purpose of the sewers was to carry off excess waters from the streets in the vicinity, but it not only discharged surface water into the stream but all the filth from the street, including a mass of dirt that accumulated in the winter and washed into the stream in the spring. The Supreme Court of Canada held that while the Municipality had at common law the right to drain its lands, it was not permitted to collect and discharge filth off the streets through an artificial channel into a natural stream to the detriment of a riparian owner. Accordingly the court granted an injunction against the city in favour of the plaintiff."

b) Any land-owner whose lands abut upon a natural water-course has the right to drain those lands into the natural stream. However, this rule is subject to certain limitations. The land-owner may <u>not</u> bring waters into a natural water-course which have not fallen upon the lands located in that watershed. Thus water from one watershed may not be diverted into another.**

I know of instances where this practise has not been observed.

These rights and obligations in common law always apply except insofar as they have been varied by statute.

You must find the statutory authority for any deviation from the common law and such statute or statutes since they take away common law rights must be strictly interpreted and read as a whole to ensure that work may be done.

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* Readings in Environmental Law for Environmental Engineers, prepared by Professor P.S. Elder, University of Western Ontario.

** Law and the Municipal Engineer, 16th Annual Workshop, Municipal Engineers' Association.

POLITICAL RESPONSE

Action is normally taken in response to the issues discussed in the previous chapters, and councils usually:

a) move to resolve the immediate needs;

b) develop a comprehensive program to effect a long-term solution.

Immediate Solutions

To reduce adverse effects and relieve the pressure of public opinion, immediate solutions are sought and implemented. In some instances attractive alternative solutions to the installation of a storm relief sewer can be found. Recently in the Borough of Scarborough a 125-acre residential area was provided relief through decentralized detention using the hydro brake concept. In other instances the solution may consist of an overflow to relieve the surcharged system. This remedy, while politically acceptable and politically expedient, may be environmentally and legally wrong. While there are many variations between these two examples, care should be taken to ensure,

1) that a successful method is not automatically deemed to be the panacea for all situations;

2) that, if a temporary solution is used, it does not become permanent.

Some workable solutions of a temporary nature often tend to relieve the situation resulting in the major problems being forgotten or dismissed.

Long-term Solutions

In the City of St. Thomas and elsewhere the long-term solution to the combined sewer problem has been one of sewer separation. The present policy of the Ministry of the Environment is that combined sewer problems be resolved by means of sewer separation. The use of storm water management techniques appeared to offer council the prospects of cost savings and rationalizing the sewerage situation in St. Thomas.

St. Thomas has experienced benefits from other studies which have sought rationalization of other major problems particularly in the conflict of railways and roads.*

Accordingly St. Thomas in competition with other municipalities, sought to have the Demonstration Project undertaken and was successful.

Evaluation of Alternatives

Mr. R.W. Kuzyk's paper will describe in detail the various alternatives facing the City of St. Thomas.

Any commitment to an otherwise long-term program must have regard for:

i) establishment of funding guidelines;
ii) growth potential;
iii) implementation based on the ability to pay.

SUMMARY

To ensure that maximum benefits are realized from the implementation of study recommendations, sound funding and planning policies must be established. A review of the various statutes, regulations and guidelines pertaining to the environment should convince anyone of the varying conflicts existing today. We are now paying and will continue to pay for the policies developed in response to the pressures exerted in the '60s.

There exists today in various circles a variance of opinions as to the matters before us. If programs in the area of storm water management are to be successful I would suggest that consideration should be had for the following:

1) that a more coordinated approach should be sought among the various Provincial ministries in an attempt to clarify and resolve some of their basic differences;
2) that funding policies should be reviewed and improved to provide assistance to municipalities in undertaking sewerage programs based on proper studies;

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* Railway Relocation Feasibility Study, DeLeuw, Cather of Canada Limited, 1971.

3) that programs undertaken should be based on a long-term implementation strategy in concert with the Provincial government based on the ability of the municipality to pay for these and other capital works;
4) that educational seminars or workshops should be provided to better educate both the elected and appointed officials.

A REVIEW OF URBAN RUNOFF MODELS

Alan R. Perks
Proctor & Redfern Limited

INTRODUCTION

Urban runoff models came into being during the last decade primarily in response to two basic needs. Firstly, traditional methods of estimating runoff were found inadequate when it came to dealing with the larger, more complicated urban drainage systems. New concerns were being expressed and considered, such as increased flooding and erosion due to urbanization, for which the older Rational theory was hard pressed to provide a reliable answer. Secondly, the increased hydraulic complexity of even medium-sized systems made it an arduous task to analyze manually, especially if several alternative schemes were being investigated. Routing and storage effects were beyond the scope of most manual analyses, and yet, these are very important aspects of the runoff cycle.

Together, these factors add up to simply doing a better job. Runoff quantity is the most important factor in drainage design, since most system elements are proportioned on this basis. Tools which enabled the designer to accurately simulate the movement of storm water through the urban system were early recognized as very helpful in drainage analysis.

The inspiration for many of today's models came from two sources. Natural hydrology researchers had developed non-urban models with good success after unit-hydrograph theory reached its peak influence. There was also a group of early hydraulic sewer models, basically computerized "design sheet" programs, which had been used with some success by engineering groups. Spurred on by the idea that urban catchments, with large amounts of impervious surfaces, were much more "predictable" than natural catchments, work began in earnest in the late 1960's, culminating in the array of urban models that exist today.

The range of models is somewhat awesome, and perhaps results in confusion and hesitation on the part of those not actively engaged in developing them. This need not be the case, however, since out of the mass of models, several have become popular and their use quite widespread.

GENERAL CHARACTERISTICS OF MODELS

Urban runoff is a continuous stochastic process which can be examined in terms of distinct sub-systems. Rainfall, depression storage, infiltration, overland flow and channel flow are the major recognized components. Most model developers have chosen to attack the simulation process through these same components.

Rainfall

Rainfall is non-uniform in time and in space. Except for very small catchments, single point rainfall measurements are not truly representative of the basin conditions. Most models allow use of several hyetographs, to be applied over different subcatchments, thereby permitting a more rigorous simulation of the storm pattern and the path of the storm. This admits to the great importance of rainfall in the complete runoff process.

Rainfall Losses

Not all the rain which falls on an area appears as runoff. Depression, detention and surface storages represent losses to the rainfall which must be satisfied before runoff can occur. These are usually modelled as a fixed amount for each simulated event and subtracted from the rainfall. Infiltration, on the other hand, is recognized as a variable process, and is usually simulated using an exponential formula such as Horton's equation. In natural watersheds, these losses play a far more significant role than in urban ones in which impervious surfaces generate so much runoff. Continuous simulation models require routines to recharge and account for these loss potentials between storm events, since these models simulate a continuous series of runoff events.

Overland Flow

In most cases, overland flow hydrographs are computed for each specified subcatchment, and these are subsequently combined and routed through the drainage system.

Kinimatic wave theory is used in many detailed models to compute the movement of overland flow. Some of the more simplified models employ a runoff coefficient approach for each applied rainfall

increment. Most models recognize the vast difference between pervious and impervious area characteristics, and model the overland flow separately. Some completely ignore pervious area runoff, which is not unreasonable for frequent storm events.

Sewer Routing

Sewer routing is perhaps the most accurately modelled portion of the runoff cycle. Conduit characteristics are usually well defined and regular, and the flow inputs are at discrete points. Routing effects, that is, attenuation and lagging of the flow hydrographs, usually increase with watershed size. The dynamic wave equation, representing unsteady, non-uniform flow is often used to perform this flow routing, but simplifications do exist, to the extent of simple time lagging. An additional complexity is occasioned by surcharging and pressure flow in sewer systems. Only the more sophisticated models have attempted to simulate these important phenomena. To date, the routines available require far more computer time, and are therefore more costly to operate than free-surface flow routing routines.

Facilities Simulation

There are numerous hydraulic facilities in a storm or combined system, such as diversions, pumps and storage devices. The more sophisticated models enable the user to simulate these facilities in various ways. The more simplified models tend to ignore them. However, in real sewer assessment studies, these facilities do play an important role in the movement and control of water.

Design Computations

Most available models are analysis tools rather than design tools. Some of the models which do feature design capabilities are limited to simply selecting a larger pipe size when a pipe surcharge is computed. Some useful design programs have been developed, but their runoff computations are often based upon the Rational formula and design sheet formats. These may be of use for certain works, but they are not suitable for storm water management work. A large part of these design programs are devoted to the various sewer criteria, such a minimum slopes,

cover, etc. A true design model which blends modern runoff theory with a complete and practical design capability has not yet become available.

Quality and Receiving Water Computations

Straightforward hydrologic and hydraulic applications are the most numerous modelling opportunities at present. Quality simulation is a more recent and less concrete concept in engineering practice. Perhaps this explains the fact that relatively few models provide quality simulation. Only three or four of the more sophisticated models attempt a complete quality simulation, including pollutant generation, dry weather flow and quality routing. The same is true of receiving water body computations. More recently, the adoption of specific quality guidelines and pollutant limits will place a greater emphasis on quality simulation and those models which have this capability.

The modelling of runoff quantity has been found to be quite reliable in spite of uncertainties in estimating model parameters. Good quantity results have been obtained using the default values in the SWMM, for example. The modelling of quality, however, is much more approximate, and reliant upon extensive calibration to obtain consistency in results. This is due to the relatively primitive state-of-the-art in formulating quality relationships and also to the infinite complexity of real pollutant sources within urban areas, which are difficult to model in a reliable deterministic way. Recent quality simulation results with SWMM are, nevertheless, showing improvement over early attempts.

TYPES OF MODELS

Three categories of models are often discussed: Planning, Design and Operational Models. While this is perhaps not the most definitive classification, it does serve to place models in a good perspective.

Planning models are the more simplified ones whose objective is to provide overall assessment information. They are characterized generally by more simplified mathematical formulations, ability to simulate continuously, use of coarser time steps, and less detail in the hydrologic and hydraulic representation of the basin. These provide information on the overall effectiveness of storage or treatment facilities

in controlling overflows, on annual pollutant and overflow discharges, and upon the frequencies with which specified runoff events occur.

Design models encompass the more sophisticated single event simulation models. They are more truly called analysis models, since their design use is by trial and error analysis. These models are characterized by very detailed mathematical formulations, fine time steps and great detail in representing the hydrologic and hydraulic elements of the watershed. These models are useful in portraying the movement of storm water and pollutants through the urban system, and in coming to grips with the problems and possibilities of storm water management.

Operational models were developed to analyze real-time data and provide operational decisions regarding transfer, storage, and routing in a complex sewer system. These models are often site specific, having been designed on the basis of a particular system. Their use is increasing as the effectiveness and benefits of system operation become more established for storm water systems.

MODEL COMPARISONS

The features of some 24 published models are compared on Table 1. The models have been arranged based upon the number of major features or capabilities each one provides. Therefore, the most comprehensive and sophisticated models are at the top, and the more simplified and restricted models are near the bottom of the table. It becomes obvious from this arrangement that only a few models attempt a complete simulation of hydrologic, hydraulic, quality and receiving water phenomena. Furthermore, the quality oriented computations are the first ones to be jettisoned in the interests of simplicity, followed by the more complex hydraulic computations. It should be noted that many of these less complex models may be quite satisfactory for the tasks they do perform.

The great diversity of these models is striking. So too, is the fact that a great amount of duplication or near duplication exists in their formulations and capabilities. A number of the models in Table 1 have become more widely known and applied in North America, for example SWMM, HSP, HVM-QQS, BNW, MITCAT, ISS, ILLUDAS and STORM. This trend will

MODEL ORIGIN	MODEL ABBREVIATION	MULTIPLE CATCHMENT INFLOWS	DRY WEATHER FLOW	INPUT OF SEVERAL HYETOGRAPHS	SNOWMELT	RUNOFF FROM IMPERVIOUS AREAS	RUNOFF FROM PERVIOUS AREAS	WATER BALANCE BETWEEN STORMS	FLOW ROUTING IN SEWERS	UPSTR AND DOWNSTR FLOW CONTROL	SURCHARGING AND PRESSURE FLOW	DIVERSIONS	PUMPING STATION	STORAGE	PRINTS STAGE	PRINTS VELOCITIES	DRY WEATHER QUALITY	STORMWATER QUALITY	QUALITY ROUTING	SEDIMENTATION AND SCOUR	QUALITY REACTIONS	WASTEWATER TREATMENT	QUALITY BALANCE BETWEEN STORMS	RECEIVING WATER FLOW SIMULATION	RECEIVING WATER QUALITY SIMULATION	CONTINUOUS SIMULATION	CAN CHOOSE TIME INTERVAL	DESIGN COMPUTATIONS	REAL TIME CONTROL	APPLIED TO [illegible]	[illegible]
HYDROCOMP	HSP	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●		●		●	●	●	●	●		●	●	
EN PROTECTION AGENCY	SWMM	●	●	●		●	●	●	●	●	●	●	●	●			●	●	●	●	●	●		●	●	●	●	●		●	●
ONTARIO MOE	CSWMM	●	●	●	●	●	●		●	●		●	●	●			●	●	●	●	●	●		●	●		●	●		●	●
DORSCH CONSULT	HVM-QQS	●	●	●		●	●	●	●	●	●	●		●	●	●	●	●	●		●	●	●	●	●	●	●			●	
WATERMATION	CSM	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●			●					●	●	●	●	
WATER RESOURCES ENGINEERS	STORM SEWER	●	●	●		●	●		●	●	●	●	●	●	●	●	●	●	●		●			●	●		●			●	
BATTELLE NORTHWEST	BNW	●	●	●		●	●		●		●	●		●	●	●	●	●	●			●					●	●	●	●	●
CITY OF CHICAGO	CHM-RPM	●	●	●		●	●	●	●		●	●				●	●	●				●		●		●	●	●		●	●
SOGREAH	CAREDAS	●	●			●	●		●	●	●	●	●	●	●	●			●					●	●		●			●	
SEATTLE METRO	CATAD	●	●	●		●	●	●	●	●	●	●	●	●	●												●		●	●	●
MIT-RESOURCE ANALYSIS	MITCAT	●	●	●	●	●	●		●		●	●		●	●	●								●			●			●	
NORWEGIAN WATER RES.	NIVA	●	●						●	●	●	●	●	●			●	●	●			●				●	●	●			
UNIVERSITY OF ILLINOIS	ISS	●	●		●	●	●		●	●		●	●	●	●	●											●	●			●
CHICAGO SANITARY DISTRICT	FSP	●	●	●	●	●	●	●	●					●	●									●		●	●			●	●
CH2M-HILL	SAM	●	●	●		●	●	●	●		●	●	●		●												●				
CORPS OF ENGINEERS	STORM		●		●	●	●	●				●		●			●	●			●		●			●				●	●
ILLINOIS STATE	ILLUDAS	●	●	●		●	●		●							●											●	●		●	●
MINNEAPOLIS ST. PAUL	UROM-9	●	●	●		●	●		●			●															●		●	●	●
UNIVERSITY OF MASSACHUSETTS		●	●			●		●	●	●					●	●										●					●
BRITISH ROAD RESEARCH LAB	RRL	●	●	●		●			●															●			●			●	●
COLORADO STATE UNIVERSITY		●	●			●			●	●					●	●															●
WILSEY AND HAM	WH-[illegible]	●				●	●		●																		●	●		●	
UNIVERSITY OF CINCINNATI	UCUR	●				●	●		●															●			●				●
UNIVERSITY OF NEBRASKA	HYDRA	●		●		●	●		●																		●				
QUEENS UNIVERSITY	QUURM	●				●	●		●																						

TABLE: 1
MODEL COMPARISONS

likely continue since these ones represent well the range of modelling capabilities required in the majority of studies.

A great deal of model testing has been done both during the development phase and also the subsequent application phase. The question of proper model calibrations has been cited as the cause of some discrepancies between model results, but in general it is felt that many models give reasonably good quantity results. For example Figure 1, from Chow [2] compares seven current models, using a complex storm pattern which might be expected to provide a good test of model infiltration and water balance routines. The range of peak flows computed by all of these models represented 25% of the recorded peak flow, and the majority of the models were within 20%. Marsalek [7] summarized some Canadian simulation results and found that 65% of SWMM results were within 20% of the recorded peak flows and volumes. In many cases, modelling discrepancies can be reduced through increased calibration effort. However, unless a number of reliable recordings are available for an area with which to verify the calibrated model, it is not advisable to pursue calibration to too fine a tolerance. Parameter values selected on the basis of a single event may not hold for other events, and therefore some weight should be given to typical or default values reported in the literature.

MODEL SELECTION

Common sense dictates that the simplest model, which will simulate the desired phenomena and with the desired accuracy, should be used. Some of the points to consider in the selection process are the nature of the problem to be solved, specific informational requirements, resources available, and program availability. At least a general knowledge of the model theory and comprehensiveness should be applied to the selection process.

Nature of Problem

Setting out a succinct description of the problem to be solved is the first step in the selection process. The scope of the problem can vary from a single pipe design (for which Rational formula methodology may be appropriate) to a complex system assessment (for which a sophisticated model

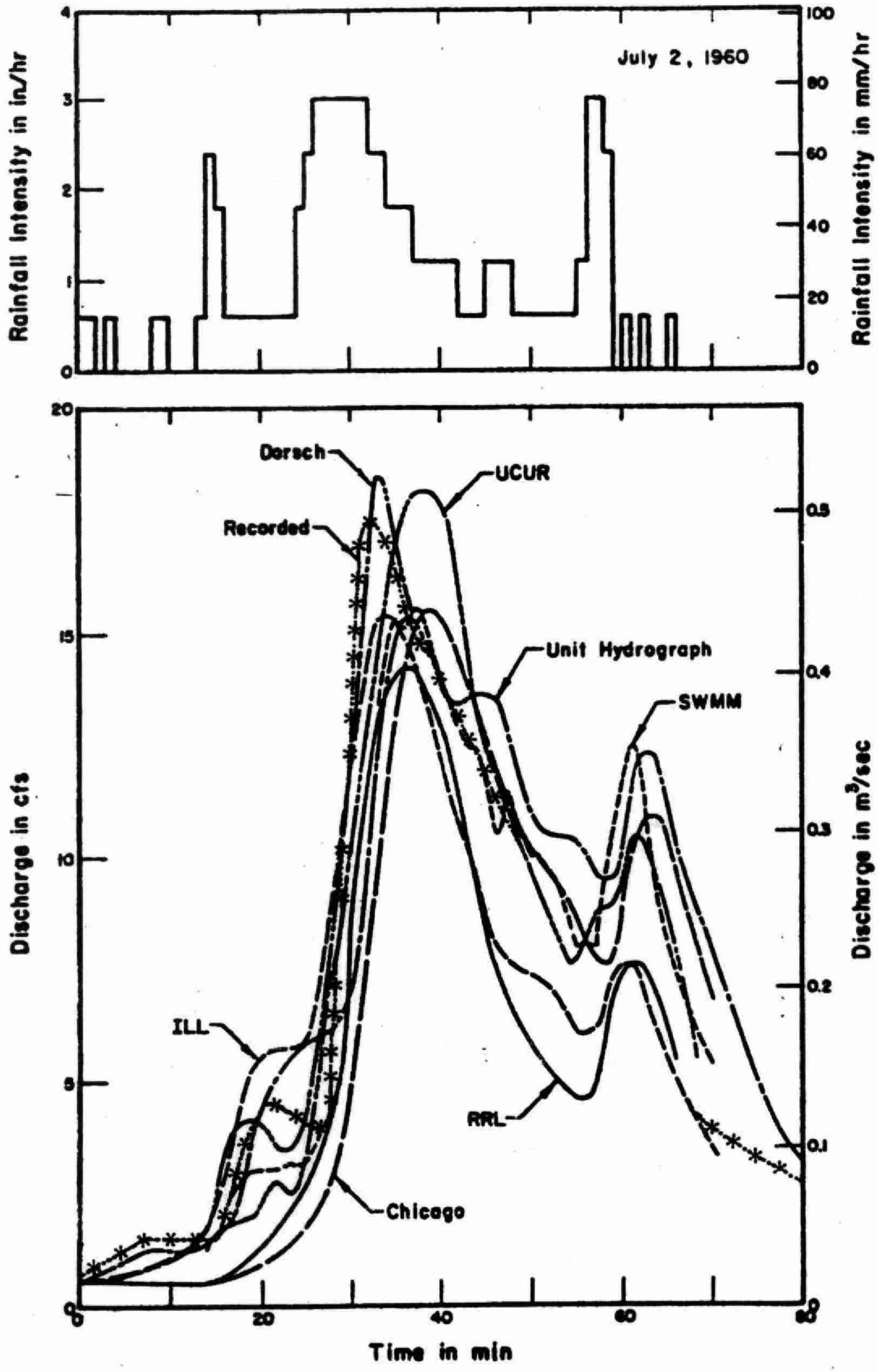

FIGURE 1. COMPARISON OF SOME RUNOFF MODELS

is necessary). The need for quantity and quality simulation, planning versus design information, and the availability of adequate data will all affect the model choice. In general, the model should be selected to suit the problem at hand, rather than vice versa.

Specific Information Requirements

If, for example, a storage facility was being investigated, the hydrograph volume as well as peak flow rates would be required, necessitating the use of a hydrograph model, rather than a simplified runoff coefficient approach. The need to compare runoff from several sub-basins would require a more detailed model such as SWMM rather than a lumped single catchment model such as STORM. The need to consider various types of innovative solutions, such as source controls, would also have a bearing on the complexity of the model required. If surcharging or pressurized design information is required, models or versions of models which produce this information would be selected.

Resources Available

The more sophisticated and comprehensive models require greater hydrologic training to operate and are generally more costly to run. The availability of suitable personnel would influence the choice. Furthermore, if little time is available and a first cut analysis is desired, use of a simpler model and limited modelling effort would be called for.

Program Availability

The user may wish to become fully involved in the analysis and technical decision-making during the study, and so the use of a freely available model such as SWMM would be appropriate. On the other hand, proprietary models offer powerful analytical techniques without the necessity for the project team to become deeply involved in the modelling process.

RECOMMENDED MODELS

A number of models shown on Table 1 have come into quite widespread use because of their capabilities, ease of usage, and cost to operate. It is difficult to categorically recommend one model over

another with similar characteristics. People have preferences in this regard, and this will continue to be so. In addition, the state-of-the-art is constantly changing and new routines and capabilities are being added. The following models are, in the author's opinion, suitable for application in the majority of drainage and water management studies facing Canadian engineers and planners at this time. Parts of the following model descriptions have been abstracted from work by Brandstetter [1], and Marsalek [7].

Non-Proprietary Models

These models are freely available and there is considerable practical experience in their application in Canada. The following three models form a hierarchy which may be applied to investigate different levels of problems:

STORM [17] - U.S. Army Corps of Engineers STORM model for preliminary planning of required storage and treatment capacity for storm runoff from single major catchments, considering both the quantity and quality of the surface runoff and untreated overflows. The model has recently been modified to include unit hydrograph computation of runoff quantity, which expands its applicability to larger watersheds. STORM may also be used to estimate annual pollutant yields, define critical events, and assess the long term impacts of urbanization.

ILLUDAS [15] - The Illinois State Water Survey Urban Drainage Simulator provides a good in-between level of hydrograph analysis suitable for the design and analysis of drainage and storage systems. It is especially useful for considering detention storage as part of storm water management plans. The model does not consider runoff quality.

SWMM [4, 11] - The Storm Water Management Model may be applied for single-event storm (and combined) flow and quality analysis. Routines have been developed for snowmelt computations, pressure and surcharge flow analysis, and

continuous simulation, although the latter has not been widely applied yet. This model provides the most comprehensive analysis capabilities for final design applications.

Other non-proprietary models

BNW [1] - Battelle Urban Wastewater Management model for real-time control and/or design optimization considering hydraulic, water quality and cost constraints, provided the hydrologic and hydraulic model assumptions are adequate for particular applications (lumping of many small subcatchments into few large catchments, neglect of downstream flow control, backwater, flow reversal, surcharging, and pressure flow).

CATD [1] - Seattle Computer Augmented Treatment and Disposal system is an example of an operating real-time control system to reduce untreated overflows. A more comprehensive computer model simulating both wastewater flow and quality, and including mathematical optimization should be considered, however, for new systems.

Proprietary Models

Several proprietary models have been widely and successfully applied, and may be utilized through contractual agreements with the developers.

HSP [1] - Hydrocomp Simulation Program for single-event and continuous wastewater flow and quality analysis provided the hydraulic limitations of the model are acceptable (approximate backwater and downstream flow control formulation, neglect of flow reversals, surcharging and pressure flow).

QQS [3] - Dorsch Consult Quantity-Quality simulation for continuous and single-event flow analysis considering most important hydraulic phenomena (except flow reversal). The model combines the capabilities of the Dorsch-HVM quantity simulation model with a new quality simulation package.

MITCAT [1] - Massachusetts Institute of Technology Urban Watershed Model for single-event flow analysis provided the hydraulic limitations of the model (neglect of backwater, downstream flow control, backwater, flow reversal, surcharging and pressure flow), or the use of a separate model for these phenomena is acceptable.

CAREDAS [1] - SOGREAH Looped Sewer Model for single-event wastewater flow and quality analysis considering all important hydraulic phenomena.

CONCLUSIONS

The state-of-the-art of urban runoff modelling is constantly changing, but there are several useful and reliable models currently available which can be recommended for use. Modelling should be seen as a tool which can expand our ability to analyze complicated systems, rather than as a substitute for judgement and experienced analysis. From this point of view, modelling is very much a part of engineering practice and potential users should not hesitate to investigate possible model applications. In all cases, the model user should become familiar with the model background and theory, and the status of its current use elsewhere.

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DATA COLLECTION, INSTRUMENTATION AND VERIFICATION OF MODELS

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INTRODUCTION

The planning and design of water resources development cannot be successfully conducted without the availability of a wide variety of basic data relating to the locality of the actual engineering works as well as to the entire region that will benefit or be affected by the project. Such a need for data is particularly strong in the development of urban water resources. The discussion herein concentrates on a particular field of urban water resources, urban drainage.

While the conventional design of urban drainage was limited to removal of surface runoff to a convenient water course, modern drainage provides for a balanced combination of natural and man-made drainage elements which are designed not only to provide an adequate flood protection for urban developments, but also to minimize the drainage impact on receiving waters. Such increasing sophistication of drainage design requires application of sophisticated design tools and the availability of a variety of supporting data.

A recent conference on urban runoff concluded [1] that though there has been progress made in the acquisition of urban field data, the needs for more and better data are growing faster than such advances are taking place.

When speaking of urban drainage data, it should be realized that such data can be produced in a variety of ways. The most reliable estimates of runoff flow rates and pollutant concentrations are field data obtained from extensive local monitoring programs. Since it is impractical to obtain such data at every point of interest, and time and budget constraints as well as physical changes in the area sometimes prevent such monitoring programs, other methods may have to be used to provide the data required. Among these methods, hydrologic modelling appears to be the best alternative. Various types of data required for the application of urban runoff models and means of collecting such data are discussed in the following.

DATA REQUIREMENTS FOR MODELLING OF URBAN RUNOFF

Two types of data are required: firstly, input data, and secondly, calibration and verification data. The requirements on such data vary depending on the purpose of the study and the modelling tool used. Consequently, only a general discussion of such requirements, with a special reference to the SWMM and STORM, is given here.

Input Data for Urban Hydrological Modelling

Data for deterministic hydrological modelling can be classified [2] into three groups:

(a) Hydrometeorologic parameters
(b) Process parameters
(c) Physical parameters

In the case of models dealing also with the water quality aspects, another category is added:

(d) Environmental quality parameters.

Hydrometeorologic parameters

Depending on the type of model used, hydrometeorologic parameters may include precipitation, evaporation, flows, and for snowmelt computations, also temperature, snow depth, wind and sunshine or solar radiation. Only the most important parameter, precipitation, is discussed here; for other parameters, the reader is referred to ref [3].

Precipitation is the most important input to a simulation model of the land phase of the hydrologic cycle.

In urban hydrology, the rain form of precipitation is particularly important. The requirements on rainfall data are rather stringent. Rainfall data, typically recorded in increments of 0.01 inch (0.25 mm) must be available at short intervals. In most design cases, such intervals vary from 5 to 15 minutes. For planning purposes, hourly rainfall data may be acceptable. Table 1 [4] offers general guidelines for the selection of time intervals depending on the size of the catchment and study objectives.

TABLE 1. RECOMMENDED TIME RESOLUTIONS OF PRECIPITATION DATA FOR URBAN RUNOFF STUDIES [4]

Watershed Type	Size Acres	Size Hectares	Time resolution minutes
Small Experimental Watersheds (for model development or calibration)	10 - 300	4 - 120	1 - 2
Large Experimental Watersheds	500 - 3000	200 - 1200	5
Data Serving for Design	up to 3000 >3000	up to 1200 >1200	5 - 10 10 - 15
Data Serving for Planning	>3000	>1200	60

Since the precipitation depth reduces somewhat with an increasing catchment area, more than one rainfall record may be required for catchments with areas larger than one square mile.

The best source of long-term rainfall data in Canada is the Atmospheric Environment Service (AES), Fisheries and Environment Canada. Data can be obtained from the AES either on magnetic tape files (hourly data), or through actual daily records on stripcharts.

Hydrologic process parameters

In deterministic hydrology, it is assumed that the relationships between the many interacting factors affecting the water balance can be defined analytically. The numeric values used to quantify the factors affecting the distribution and movement of water are termed parameters. The parameters which quantify the movement and storage of water in and on the land surface of a catchment are called process parameters and are the key to catchment response. They include infiltration, surface and lower zones storage, interception, overland flow parameters, runoff coefficients, interflow, transpiration, snowmelt parameters and others. Only some of these parameters are important in urban hydrology, namely, infiltration, surface storage, overland flow parameters and runoff coefficients.

Although some process parameters can be measured directly, in some cases this may be difficult or impractical and the numerical values of these parameters are obtained either by calibration or transposition from other similar catchments.

Infiltration. The importance of infiltration in urban catchment hydrology depends on the catchment imperviousness. In downtown areas with high imperviousness (80% or more), pervious areas contribute very little to the total runoff and an accurate estimate of infiltration is of little importance. On the other hand, the pervious surface may contribute significantly to the total runoff from partly developed (low imperviousness) areas and a good estimate of infiltration is needed.

Best estimates of infiltration rates are obtained by calibration of simulated runoff hydrographs against the observed ones [5]. The variation of the infiltration rate, i(inch/hr), during a storm is frequently described by the Horton formula:

$$i = f_o + (f_i - f_o)\, e^{-ct}$$

where: f_o = minimum infiltration rate (inches/hour),
f_i = maximum infiltration rate (inches/hour),
c = decay rate (1/sec),
t = time from the start of rainfall (sec).

The Horton formula contains three coefficients f_o, f_i, and c, which can be easily calibrated. This contributes to the widespread use of the formula in urban hydrology, even though more advanced approaches to infiltration have been developed [6]. For numerical values of the above noted coefficients, references [7, 8] should be consulted.

On impervious areas, zero infiltration is typically assumed.

Surface storage. The surface storage consists of the depression storage and storage on the overland flow plane. The former storage is typically assigned a constant value, the latter storage varies during the computations. Basically, the surface storage creates a time lag between the surface element inflow (i.e. rainfall) and outflow (runoff).

Depressions on natural surfaces vary greatly in geometry. The depth of depression storage may be determined by calibration, or by transposition of data from other urban catchments. Some guidance can be obtained from the data in Table 2.

TABLE 2. SURFACE DEPRESSION STORAGE ON URBAN CATCHMENTS

	Surface Depression Storage (inch)	
	Impervious	Pervious
SWMM Default Value	0.062	0.184
Calibration Values	0.02 [9], 0.04 [10]	0.10 [11]

Overland flow parameters. Examples of such parameters are the overland flow roughness and the width of overland flow plane (under some circumstances, this is a physical parameter). The roughness is usually described by the Manning coefficient n. The values of n = 0.013 and n = 0.25 are recommended [8] for impervious and pervious areas, respectively.

The width of the overland flow plane as used e.g. in the SWMM model may become a process parameter. Though this width is related to the physical width of the catchment it may assume a function of a process parameter derived from calibration [12]. This is particularly true for coarsely discretized catchments. The width of the flow plane may then deviate significantly from the actual width in order to simulate properly the catchment response.

Runoff coefficient. In simple runoff computations, the runoff coefficient can be used as a crude index which combines some or all factors affecting runoff. Such an approach is for example taken in the STORM model [13]. Numerical values of runoff coefficient are listed in design manuals [14, 15].

Physical parameters

The definition of physical parameters of a catchment and of its subcatchments is a relatively straightforward task. The detail of such data depends on the level of modelling, and under some circumstances, the collection of physical parameter data is a tedious task contributing significantly to the total cost of modelling.

At the planning level, a very rough characterization of the catchment may be acceptable. In fact, the details of the sewer system may be disregarded at this level. At the design level, however, more detailed information is gathered from aerial photos, drainage maps, sewer plans, topographic maps, soil maps, etc. Below are listed the types of information which may be of interest in detailed modelling of quantity and quality of urban runoff [16].

The catchment should be characterized as to area; impervious area; effective impervious area (directly connected impervious area); pervious area; contributing pervious area (pervious area that would, if subjected to heavy rainfall, contribute runoff to the drainage system); street lengths, widths, slopes, surface type and condition; soil types; length of curbed streets versus non-curbed streets; land-use distribution; location and size of catch basins; inlet-characteristics; ground-surface elevations at pipe junctions; conduit invert elevations and material types; conduit and open-channel length, slopes, sizes, geometry and friction factors; and pertinent characteristics of special drainage features such as detention basins, and any other features special to the catchment of interest.

Environment quality data

Investigations of runoff quality require supporting data referring to sources of pollutants and measures for control of pollutants. Though some of these data could fit into the previously specified categories, it appears preferable to treat the environmental quality data separately. Note also that this type of data is needed only in the water quality oriented studies of drainage.

Sources of Pollution and their quantification. Pollutant loads are introduced into storm water and combined sewage from the following sources:

(a) Rain water contamination
(b) Land surface
(c) Soil erosion
(d) Dry weather flow
(e) Deposits in sewers and catch basins.

The contamination of rain water is typically neglected in water quality studies of urban runoff.

The accumulation of pollutants on the land surface represents an important source of pollution. Pollutants accumulate during the periods of dry weather and are washed off during storms. Such accumulations can be computed, for a particular area, by multiplying the dry weather period in days by the daily loading rates. Such loading rates vary with the type of pollutant and with the land use. Reference [13] is a good source of loading rates.

Urban soil erosion may contribute significantly to the total emission of solids from the catchment, particularly in the case of catchments with ongoing construction activities. The resulting soil loss per unit area is described by the Universal Soil Loss Equation [17]. This equation was used recently to predict the average soil loss for a given storm or time period and for details the reader is referred to reference [18].

Dry weather flow is another major source of pollutants included in the modelling of water quality of combined sewage. Flow records and composition data are available in many locations and can be readily used in computations. If such data are not available, a number of references can be consulted [8, 14].

The mechanism of deposition and resuspension of pollutants in sewers may significantly affect the composition of sewage, particularly in combined sewers with flat slopes. Such mechanism is not well understood at present and is quantified indirectly through model calibration [8].

The contribution of catch basins to the total emission of pollutants is usually of secondary importance [18].

Pollution control measures. Street sweeping and various forms of treatment are common methods of control of pollution due to urban drainage. Pollutants accumulated on the catchment surface are partly removed by sweeping streets. This pollutant removal can be quantified if the frequency and efficiency of sweeping streets are known [8].

Various methods of treatment of storm water and combined sewage have been developed [18]. Such methods range from primary clarification

to combinations of several treatment processes. For details of such treatment processes, see ref. [8].

Cost data

Proper design of urban drainage minimizes the cost of flood damages due to underdesign and economic inefficiency due to overdesign [3]. Such design can be arrived at by developing the cost-benefit relations in which the cost is the drainage construction costs and the benefits are the prevented flood damages. The latter data, flood damages, are rather scarce and that prevents a wider use of the cost-benefit analysis in urban drainage design.

Water quality benefits can be hardly expressed in dollars as required in the cost-benefit analysis. As an alternative, water quality objectives are specified and a design scheme meeting these objectives at a minimum cost is sought. Such a procedure requires the knowledge of the cost of various quality control measures. For a first-cut analysis, such costs can be obtained from references [8, 12].

Input data for the SWMM and STORM

For a better appreciation of requirements on input data in urban hydrologic modelling, input data for two selected models, the SWMM and STORM, are listed in Table 3.

Note that all the data listed in Table 3 are needed only in those cases when the entire model is applied. Some of the data listed can be transposed from other catchments or be supplied by the model as default values. Only in detailed and complex design simulations does one need to deal, to various extents, with all the types of input data listed in Table 3. The selection of an appropriate detail of the input data can be aided by model sensitivity analyses [12].

Calibration and Verification of Models

The calibration of a runoff model is a procedure in which model parameters are manipulated to reproduce the response of the catchment under study with some range of accuracy. Calibration is not a problem unique to hydrologic simulation. Any hydrologic procedure will yield better results if tested against observed data and any constants are appropriately fixed by data from the area studied.

TABLE 3. SWMM AND STORM INPUT DATA [19]

SWMM Model	STORM model
Rainfall data, antecedent dry days	Hourly rainfall
Subcatchment descriptions including area, overland flow width, slope, roughness coefficients, infiltration rates, percent imperviousness	Area of drainage basin
Land use, population data	Percent of total area in each of 5 land use groups
Street sweeping frequency and number of passes	Average percent imperviousness of each land use group
Soil erosion data	Runoff coefficients for pervious and impervious areas
Pollutant loading and generation factors	Feet of gutter per acre for each land use group
Sewer layout, shapes, dimensions, slope, roughness	Depression storage available on impervious areas
Specifications of flow control devices	Treatment rate
Infiltration data	Hourly rainfall
Dry weather flows	Daily rate of dust and dirt accumulation per 100 feet of gutter for each land use group
Catch basin data	Pounds of pollutants per 100 pounds of dust and dirt
Treatment and storage facility data	Street sweeping frequency and efficiency.
Tidal variations, water surface elevations and areas, water depths and roughness coefficients for receiving waters	
Receiving water boundary conditions	

Main advantages of calibration are as follows:

(a) Calibration produces estimates of input parameters that are difficult to measure directly (e.g. infiltration rates, pollutant loadings).
(b) Calibration compensates, to some extent, for imperfections or omissions in the model structure.
(c) Calibration together with verification lend reliability to the model predictions.

Once a model has been calibrated against a set of calibration data, it should be verified with a set of data separate from that used in model calibration. Model verification consists of a rational analysis of both the computed output and any empirically derived parameters. Additionally, to provide a proper verification, the computed model output should be compared with observed output (e.g. runoff flows).

Before proceedings with the actual calibration, goodness of fit and accuracy criteria need to be established. A wide variety of such criteria are described in the literature [2]. In urban drainage, criteria for peak flow rates, runoff volumes and times to peak flow are usually sufficient [2].

Several methods of calibration and parameter optimization procedures exist [2]. Complex urban runoff models are typically calibrated by a trial and error procedure. Model parameters are systematically varied until the model output is within the specified range of accuracy as compared against the fixed observed output. The selection of parameters to be calibrated is greatly aided by the sensitivity analysis specifying how model parameters affect the output.

Note that direct model calibration (i.e. in the catchment studied) is not always necessary or possible. In simulations of runoff quantities, calibrated parameters are often transposed from analogous catchments in the same region. A similar procedure may be used for quality simulations, however, with a lesser degree of confidence.

<u>Calibration/verification data</u>

Calibration/verification data for urban runoff models generally consist of synchronized observations of rainfall, runoff hydrographs,

and runoff pollutographs for a number of events. The following aspects of calibration/verification data are of major interest:

(a) accuracy of data,

(b) number and type of calibration/verification events.

Accuracy of calibration/verification data. Accuracy of calibration data will affect the calibrated values of model parameters, and consequently, the accuracy of predictions done with the calibrated model. Systematic errors in calibration data may have a dramatic impact on the accuracy of predictions. Random errors are less likely to affect the mean of a set of measurements in a sufficiently large sample. During the period not used for the calibration of model parameters, the errors in the comparison of measured to observed phenomena are likely to be greater than the data errors, because of errors in the fitted parameters. The non-linearity of hydrologic processes precludes theoretical description of the mechanism by which errors in data are transferred to model parameters and then combined with input data errors in the test period to produce errors in the simulated output [16]. A few general considerations can be described.

For flow simulations, random errors in input data such as rainfall are usually compensated for by adjustments in the loss functions (infiltration, detention storage), while random errors in output such as flow are usually compensated for in the routing function [16].

Errors in water quality simulation are particularly troublesome to define. Principal problems include the high variability of runoff composition and the almost complete lack of knowledge as to processes [16].

Desired accuracies of observed phenomena are specified [16] as follows:

Flow data	± 5%
Precipitation	lesser accuracy than flows - probably of the order 10%, avoid systematic errors (undercatch)
Water quality data	± 25%

Number and type of calibration events. A manual on instrumentation and analysis of urban storm water data [16] suggests that about 10 - 15 events may be required for model calibration and the same number for model verification. Such a sample would be large enough to reduce the effect of random errors on the fitted parameter values to an acceptable level. While the above numbers may represent an ideal situation, in urban drainage design, one has frequently to work with a much lesser number of observed events. It should be realized that even a small number of observations of high accuracy will improve model predictions. On the other hand, model calibration against observations of poor accuracy is meaningless. The number of events used for calibration is a compromise between the ideal number (say 15) and the number of events which are available or can be monitored within the time and budget constraints.

Prior to calibration, the calibration data should be thoroughly inspected and obviously erroneous data eliminated. An example of such inspection is computing the ratios of the total runoff to the total rainfall.

Finally, one should realize that not only the number but also the type of events is important. Even a large number of observed minor storms will not yield any information on the maximum infiltration rates if the input of rain water remains well below such rates. Another example is the need to observe storms with various antecedent dry periods in order to assess the pollutant loading rates in the catchment.

Considerations in calibration of the SWMM (Runoff quantity and quality only)

The following example of considerations to be made in calibration of the SWMM (Runoff Block) was adapted from the SWMM User's Manual, Version II [18].

Runoff quantity. Assuming that a careful and thorough evaluation of physical data (such as area, ground slope, percent imperviousness) has been made, the user has flexibility to adjust seven quantity input parameters:

1) resistance factor for impervious areas,
2) resistance factor for pervious areas,

3) surface storage on impervious areas,
4) surface storage on pervious areas,
5) maximum rate of infiltration,
6) minimum rate of infiltration,
7) decay rate of infiltration.

The first two parameters are likely to affect the timing of hydrographs; the last five parameters will primarily affect runoff values as well as timing. The number of parameters to be adjusted can be further reduced by sensitivity analysis. In the example [18] presented here, the following findings were made for a particular drainage area and a single storm:

The resistance factor for impervious areas had little effect. A 100 fold increase in magnitude resulted in an 18 percent increase in surface storage, but resulted in only a 1.5 percent reduction of the total gutter flow (runoff volume). A 50 fold increase in the resistance factor for pervious areas had no effect. Impervious area surface storage (or detention depth) was more important: increasing its magnitude from 0.001 inch to 0.200 inch resulted in a 100 percent increase in surface storage, and an 18 percent decrease in the total gutter flow. The model was totally insensitive to a 50 fold increase in the magnitude of the pervious area surface storage parameter. Variation of the maximum rate of infiltration from 1.50 inches per hour to 6.00 inches per hour produced no effects on runoff volume. Variation of the minimum rate of infiltration from 1.50 inches per hour to 0.01 inches per hour (holding the maximum rate and the decay rate constant) resulted in a net decrease of 8 percent in the total volume of infiltration. The runoff volume increased by 75 percent as a result of the decreased infiltration.

The relative effect of the maximum versus minimum infiltration rates is affected by the decay rate. As this rate is increased, the infiltration curve moves rapidly towards its minimum value. As this rate decreases, the infiltration curve remains near its maximum value longer.

The results presented above pertain to a specific drainage basin (41 subcatchments, 134.59 acres) subjected to a specific storm event. Results will vary somewhat depending on the rainfall and the geomorphology of the drainage basin. However, the same parameters should

remain sensitive on a relative basis. In summary, the model is considered sensitive to the following quantity input parameters for calibration purposes:

1) surface roughness for impervious areas,
2) detention depth for impervious areas,
3) maximum or minimum values of infiltration, the former only for values of the decay rate less than the default value.

Runoff quality. If the user has measured values that indicate different pollutant loading from those built into the SWMM as default values [18], the new loadings can be substituted into the model.

An accurate computation of suspended solids requires erosion data (where applicable). The most significant parameter in the quality simulation is land use classification, since the APWA loading rates are a function of land use types. Other important factors include: (1) the number of dry days preceding the storm event, (2) the street cleaning frequency and number of passes, (3) the volume of water trapped in the catch basin between storm events, and (4) the BOD (COD) demand exerted by the trapped fluid in the catch basin.

The number of dry days can be determined from rainfall records and should not be varied for calibration. The volume of trapped water in the catch basins can usually be determined from sewer plans obtainable from the municipality. In the event of several catch basin types, an average value may be used. If this estimate is not accurate, this parameter may have to be adjusted during calibration. Few municipalities measure the catch basin organic demand, thus the user should assume the default value and adjust this parameter according to the results. The street cleaning frequency and number of passes may also be obtained from the municipality.

Neither the catch basin volume nor the initial concentrations had dramatic effects on runoff quality simulations for a sample run. All catch basin effects decay as the runoff continues, and disappear entirely after about the first hour of the storm, depending on its magnitude.

Calibration of the STORM

Mathematical formulations quantifying the runoff process in the STORM are much simpler than those in the SWMM. Consequently, a lesser number of parameters is adjusted in calibration. The brief discussion presented here is limited to the rainfall/runoff computations only since the runoff quality approach in the STORM model is similar to that in the SWMM model which was discussed earlier.

In the STORM model, the runoff quantity is calculated on an hourly basis using the following expression [13].

$$R = C(P - f)$$

where: R = urban area runoff in inches per hour;

C = composite runoff coefficient dependent on urban land use;

P = rainfall plus snowmelt in inches per hour over the urban area; and

f = available urban depression storage in inches per hour.

If observations of precipitation and runoff are available, calibrated values of the composite runoff coefficient C and the depression storage f can be found analytically using, for example, the least squares approximation.

COLLECTION OF URBAN HYDROLOGICAL DATA

Full potential of hydrologic simulation can be realized only if some hydrologic data are available for a city. Note that much of such data is required for any method of analysis and is not pertinent only to hydrologic simulation which is stressed in this presentation.

Network Design in Urban Hydrology

The collection of urban hydrologic data can be considered as a hydrological network design problem. The objective of such a design is defined here as to specify the number and arrangement of the data-acquisition points which in conjunction with a selected runoff model would yield the minimum error for a given cost, or would indicate where to add observation points to produce the maximum benefit.

The definition of a network for hydrologic data is a matter of some controversy [20]. The following definition [21] was adopted here:

"A network is an organized system for the collection of information of a specific kind. Its component parts must be related to one another; that is, each station, point, or region of observation must fill one or more definite niches in either space or time."

A possible classification of hydrological networks appears in Figure 1 [20]. The networks are classified according to their purpose, processes observed, type and frequency of observations, type of field record, length of record, standards of precision, nature of spatial design, and maintenance and quality control. This classification does not bring out differences in levels of intensity of information requirements. Such consideration is made for example in the classification shown in Figure 2 [20]. It is apparent from the latter classification that most of the urban hydrological networks fall into level III, i.e. data are gathered for particular operational, legal and administrative purposes relating to local water resources management. Such networks are rarely subject to design. This statement was also confirmed by the findings of a recent Engineering Foundation Conference which concluded that network design is generally the most neglected part of urban data acquisition programs [16].

The discussion of urban hydrological networks follows the classification introduced in Figure 1.

Purpose of networks. Among the purposes of urban networks, the most frequent are project planning and design, followed by operation, monitoring and research. The first two items, planning and design are closely related to computer modelling of hydrologic processes. A good example of operational data networks are those employed in the computer-operated combined sewer systems [22].

Typical networks are multipurpose networks. Transferability of data to other catchments within an urban area is of utmost importance.

Processes observed. Most frequently, the following processes are observed: precipitation, runoff quantity and quality, and eventually, changes in storage.

Type and frequency of observations. Precipitation and flows are measured continuously, or intermittently i.e. only during the periods of wet weather. Water quality is monitored periodically.

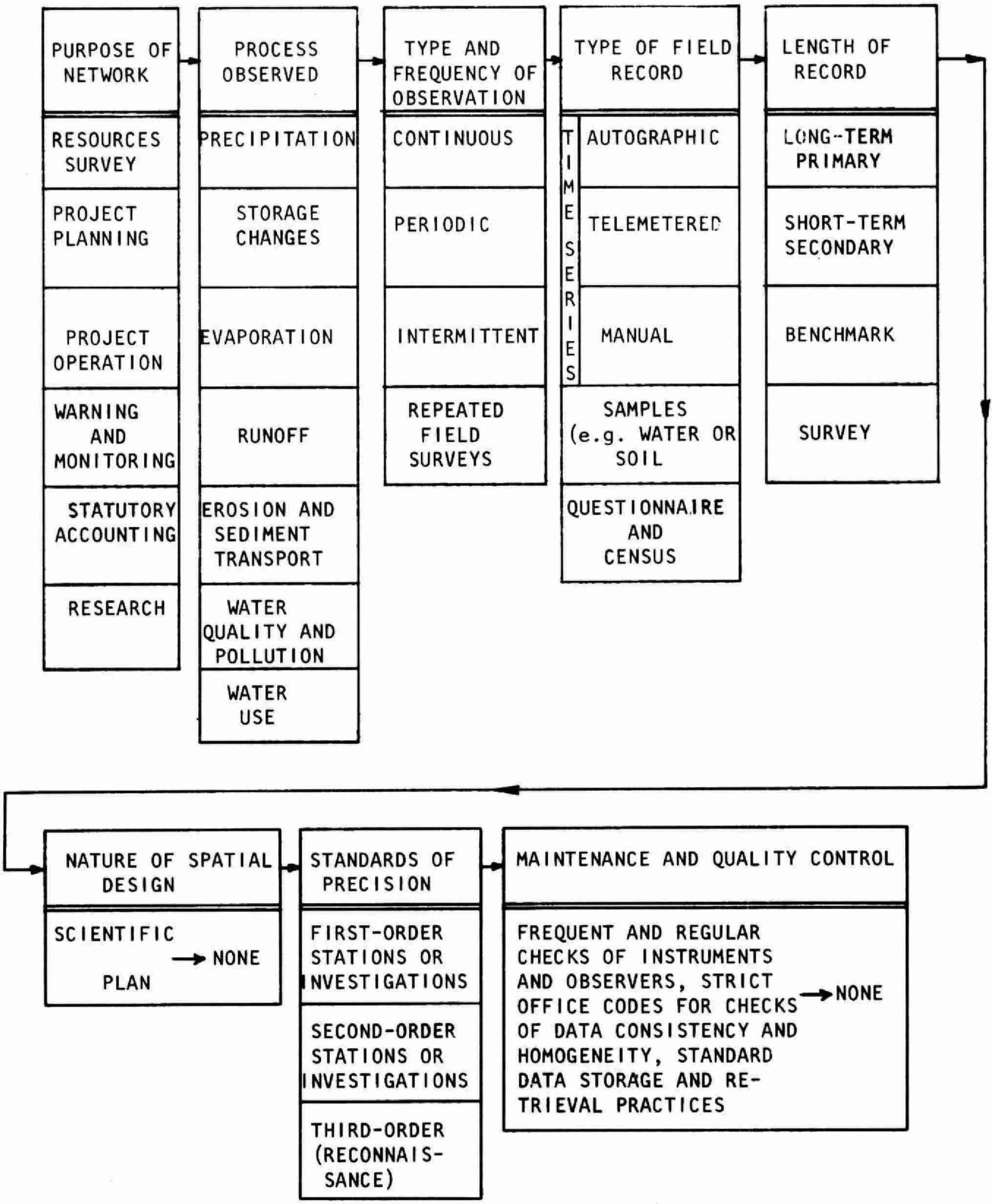

FIGURE 1. A SUGGESTED NETWORK CLASSIFICATION [20]

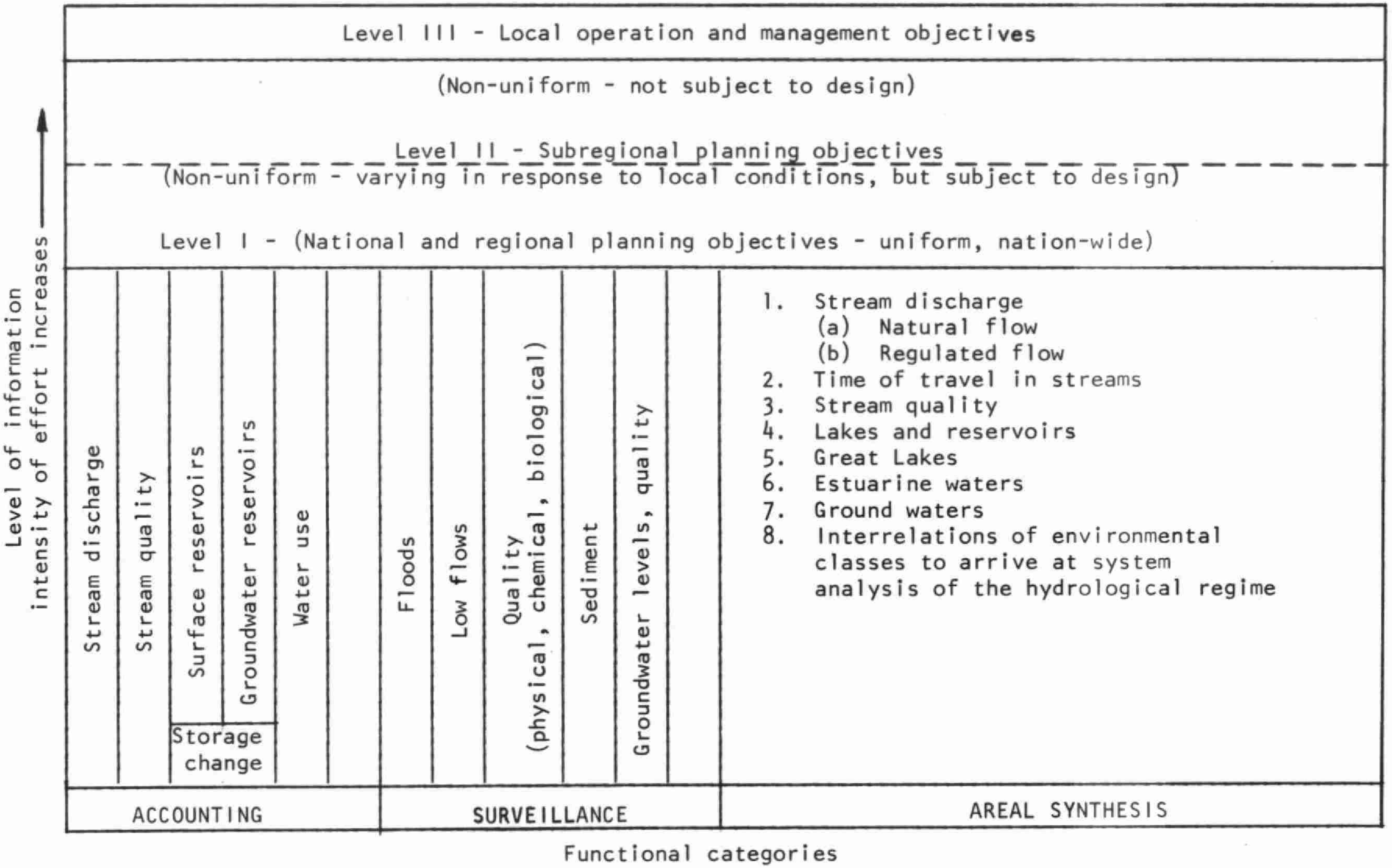

FIGURE 2. SCHEMATIC DIAGRAM SHOWING RELATION OF LEVELS OF INFORMATION TO FUNCTIONAL CATEGORIES IN THE U.S. NATIONAL WATER DATA NETWORK [20]

Type of field record. Most common are autographic records. Water quality is monitored by means of sampling. For large networks or operation of combined sewer networks, data telemetering is employed. The use of recorders producing computer compatible records (magnetic or punched tapes) is economical when large volumes of data are collected.

Length of record. Typically, short-term secondary records are produced. Depending on the purpose, the data should be collected for the shortest period acceptable. One year, or full seasons of interest are considered as a minimum duration in engineering studies, if the program proceeds successfully [16]. In other cases, the program duration may be dictated by the need to monitor a desired number of calibration/verification events.

Standards of precision. These standards were briefly discussed previously in this paper. The aforementioned accuracies would correspond to those specified for the first order stations. Lesser accuracies may be fully acceptable in some engineering studies.

Nature of spatial design. Spatial design in urban networks has two facets - firstly the number (density) of data acquisition points, and secondly the location of such points. Scientific spatial design is rarely applied in urban networks, although methodologies for some aspects of such design are available [16]. One such methodology [23] makes it possible to design an optimal rain gauge network in terms of the number and location of stations. The resulting cost and mean square error of estimation are computed.

Other spatial considerations involve selection of the catchments to be monitored within the urban area, and siting and density of instruments.

The effectiveness of hydrologic modelling in the long run will be largely given by the ability of modellers to estimate model parameters on basins which have no data for calibration of the model being applied. Estimation of these parameters can be achieved by transposition of data from the instrumented test catchments. Each monitored catchment should be therefore viewed as a sample of the catchments in the urban area studied. It is imperative that the samples chosen include a set of catchments which are representative of an area's catchment land-uses,

types of development, sizes, soil types, hydrologic regimes, etc. [16]. Selection of representative samples is necessary to arrive at a set of transferable model parameters which cover the variations among catchments for the entire urban area.

According to ref. [16] catchment selection begins with an inventory of catchments in the urban area characterizing them at least by size; land use (present and projected); drainage type (fully sewered, degrees of partially sewered, and non-sewered); and relationship to major streams, lakes or estuaries within the area of interest, in terms of sewer outfall and tributary stream entry points, and all previously collected data. For further details, see ref. [16].

The need for multiple rain gauges to characterize the spatial variability of rainfall has been long recognized; however, the need for multiple flow/water quality monitoring stations to characterize the spatial variability of hydrologic and water quality processes has been virtually ignored [16]. Though recommendations were made to establish a minimum of two flow/water quality monitoring stations on a catchment [16], such measures may be impractical and costly.

Maintenance and quality control. Maintenance and quality control are often neglected in urban networks. Such neglect together with frequent malfunctions of instruments then results in loss of data. It is not unusual that less than 50% of all the events are successfully and completely monitored. To avoid such loss of data, frequent and regular checks of instruments are recommended together with checks of collected data consistency and homogeneity.

Instrumentation

Proper instrumentation of catchments is imperative for a good data collection program. Catchment instrumentation includes rain gauges, flow gauges, wastewater samplers and recorders. These instruments and their application in urban hydrological studies were reviewed in several recent reports [4, 24, 25]. Only a brief discussion of catchment instrumentation follows.

Rain gauges. Precipitation data consists of point precipitation and of the areal distribution of precipitation. Such information can be

obtained from a network of several recording rain gauges installed within the studied area. The tipping bucket rain gauge of 0.01-inch (0.25-mm) per tip capacity is particularly suitable for this purpose. A good time resolution, frequently five minutes or shorter, is required. Two gauges are sufficient for catchment areas up to 10 km^2 (4 sq mi), and for up to 50 km^2 (20 sq mi) three gauges are recommended. Time resolutions of rainfall data recommended for urban runoff studies were given in Table 1.

Flow gauges. Runoff flow rates should be recorded continuously at one or more points. Whenever feasible, runoff flows should be measured at the outfall, outside the sewer system. Conventional constriction flow meters such as weirs or flumes can be used.

If it is necessary to measure inside the sewer system, and the sewer pipe is not frequently surcharged, an inexpensive vertical slot weir or a flume (e.g., Palmer-Bowlus flume) are applicable. For frequently surcharged pipes, a dual free-pressurized flow meter such as the U.S. Geological Survey Sewer Flowmeter or an acoustic flow meter should be used.

The acceptable accuracy of runoff flow measurements is 5 to 10%.

Characteristics of selected liquid level sensors and an overview of sewer flow measurement techniques are given in Tables 4 and 5, respectively.

Runoff quality is commonly determined from the laboratory analysis of grab samples collected in the field. Such samples are collected sequentially by automatic samplers. A sampling interval as short as 5 to 10 minutes may be required. The first sample should be collected as closely to the beginning of runoff as practicable. In the currently common approach, a constant sampling interval is selected on the basis of experience and the size of the studied area. A review of ten urban runoff studies (i.e., storm water runoff as well as combined sewer overflows) indicated the sampling intervals shown in Table 6.

Other factors to be considered in the selection of a sampling interval are the precipitation time-distribution and the watershed hydrologic response. These two factors influence the runoff flow rates to which the storm water quality seems to be related. Consequently,

TABLE 4. CHARACTERISTICS OF SELECTED LIQUID LEVEL SENSORS [4]

Type of Liquid Level Sensor	Application		Typical Installation			Input Power Options (Sensor Only)		
	Free flow	Pressure Flow	Directly in sewer	In Sewer but with some protection	In a stilling well	DC	AC	Other
Capacitance Probe	X	-	-	X	X	X	X	-
Dipper Probe	X	-	X	-	-	X	X	-
Floats	X	-	X (Scow float)	-	X	-	-	none required
Pneumatic Probe	X	X	X	X	-	X	X	X (compressed gas)
Acoustic Probe	X	-	X	-		X	X	-

high intensity and low duration summer storms on fast responding watersheds will call for shorter sampling intervals and vice versa.

The first sample should be collected as closely to the beginning of runoff as feasible. This can be achieved by activating the sampler by the first impulse from the precipitation sensor, or better, by the rise of the water level in the sewer by a preselected increment.

Some electronic liquid level sensors (e.g., capacitance probes, Manning Dipper, ultrasonic probes, etc.) can be equipped with alarm relays and these are then used to close the power supply circuit of the sampler when flow reaches the selected level.

The minimum size of samples is about 1000 ml. Great care has to be devoted in order to avoid systematic errors in the sampling. The first step in this direction is to locate the sample intake at a cross-section where the sampled medium is rather homogeneous. The capability of the sampling apparatus to collect solids should be evaluated, mainly with regard to the intake orientation and the intake nozzle and line velocities.

TABLE 5. OVERVIEW OF SEWER FLOW MEASUREMENT TECHNIQUES [4]

TECHNIQUE	FREE FLOW	FREE AND PRESSURE FLOW	APPLICABLE AT OUTFALL	APPLICABLE MAN-HOLE	APPLICABLE SEWER PIPE	ESTIMATED ACCURACY	COST RANGE*	RECOM-MENDED
Depth Measurement only	X	X**	X	X		20%	L	No
Depth and point velocity	X		X	X		5%	H	Yes
Specific energy	X			X		20%	L	No
Depth and chord velocity	X	X	X	X	X	3%?	H	Yes
Weirs -								
Rectangular	X		X			5%	L	Yes
V-Notch	X		X			5%	L	Yes
Trapezoidal	X		X	X	X	5%	L	Yes
Vertical slot	X		X	X	X	5%	L	Yes
Flumes -								
Leopold-Lagco	X		X	X		5%	M	Yes
Parshall	X		X			5%	M	Yes
Palmer-Bowlus	X		X	X	X	5%	M	Yes
U.S.G.S.	X	X	X		X	5%	M-H	Yes
Univ. of Illinois	X	X	X		X	5%	M-H	Yes
Tracers	X	X		X		5%	M	No

*: L = Low cost; H = High cost; and M = Medium cost.

**: Measuring pressure drop between two manholes.

TABLE 6. SAMPLING INTERVALS IN URBAN RUNOFF STUDIES [4].

WATERSHED SIZE		SAMPLING INTERVAL	24 SAMPLE CYCLE DURATION
(Acres)	(Ha)	(Minutes)	(Hours)
10	4	5	2
50	20	5-7.5	2-3
100	40	5-10	2-4
500	202	5-15	4-6
1000	455	5-15	4-6
2000	809	15	6
3000	1214	20	8
5000	2023	25-30	10-12

To reduce the loss of quality data owing to sampler malfunctions, two samplers may have to be installed and operated in parallel.

The selection of water quality parameters investigated in urban runoff studies is affected by a number of considerations. For some advice in this regard, see ref. [16].

A good time synchronization between the recordings of precipitation, runoff flow and sample collection can best be ensured by recording all this information on the same chart or tape.

Practical Aspects of Data Collection

Some practical aspects of data collection were dealt with in the preceding section. Additional discussion presented here deals with data analysis and reduction, data storage and management, and cost of collection programs.

Data analysis and reduction

The collection and analysis of data should be simultaneous. Delays in data reduction and analysis can reduce the efficiency of the data collection program and result in loss of data. Expedient analysis of data often reveals instrument malfunctions which could remain undetected for long periods of time. Prompt analysis of data may also lead to changes in the data collection procedures.

Data reduction starts with a thorough inspection of all records. The accuracy of data is documented and equipment problems which were recorded in the field book or are apparent from the records are noted. Only data of acceptable accuracy are further processed.

Depending on the type of recorder, rainfall and flow records may have to be digitized.

Analysis of the collected samples requires strict adherence to standard procedures [16]. Water quality of runoff is expressed in constituent concentrations, mass flows and eventually the total mass emitted during an event. The need for good synchronization of sampling and flow records is obvious.

Data storage and management

All data should be converted to computer compatible forms (cards or magnetic tapes) for storage. A storage format for an Urban Rainfall/Runoff Data Base was proposed by the University of Florida [26]. Such a format consists of introduction, description of the urbanized area, catchment description, and observed data. Observed data consist of rainfall hyetographs, runoff hydrographs and runoff pollutographs.

Data collected should be plotted at an early stage. A single graph should contain storm hyetograph, hydrograph and water quality data. Such plots are helpful for data inspection and also offer an understanding of catchment response in terms of runoff quantity and quality.

Finally, well-documented and reliable events are selected for further use, such as model calibration and verification.

Cost of data collection programs

The costs of data collection programs vary depending on the purpose and scope of such programs. The costs can be divided into two categories, the initial costs associated with the establishment and instrumentation of the catchment, and operating costs. In the former category, the costs of equipment and its installation are the main items. An instrumentation system consisting of a tipping bucket rain gauge, weir, water level sensor, automatic wastewater sampler, and recorder will cost more than $8,000.00. Installations with measuring flumes or a back-up sampler may cost even more, close to $20,000.00.

Operating costs consist of labour costs (site visits and maintenance), sample analyses and costs of supplies.

Site visits are particularly frequent if the collection of water samples is part of the program. Samples have to be collected shortly after the storm and the sampler reset for the next event. The collected samples are then delivered to an analytical laboratory for further processing. The costs of sample analyses depend on the number of parameters studied. Costs of the order of \$60.00 to \$100.00 per sample are not unusual.

Data collection programs dealing with runoff quantity only are less expensive. The cost of equipment is reduced for the cost of a sampler (about \$4,000.00). The analytical costs do not apply and the frequency of site visits can be reduced.

CONCLUSIONS

Increasing sophistication of urban drainage design calls for application of innovative design tools, such as hydrologic modelling. The full potential of hydrologic modelling can be realized only if sufficient hydrologic data are available for the studied area. Such data consist of various input data and calibration/verification data.

The collection of calibration data consisting of rainfall, runoff quantity and quality, and supporting data, should be considered as a hydrological network problem. The ultimate goal of such collection programs should be to produce, in conjunction with an analytical tool (e.g. a hydrological model), urban runoff flows and their composition at any desired point in the urban area. Though the costs of such data collection programs are appreciable, these costs are not excessive in relation to storm drainage costs or benefits derived from improved design.

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APPLICATION OF COMPUTER MODELS FOR STORM WATER MANAGEMENT

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INTRODUCTION

The object of past drainage studies was generally straightforward: sizing of pipes, culverts or channels for rapid removal of runoff caused by a storm with a given frequency. The success of the Rational formula and its persistence in engineering practice, despite its known shortcomings, may be explained partly because it provided a quick estimate of peak flow and it was relatively well understood by all those involved in the studies. Design of sewer systems based on this approach leads to a quick removal of storm water and increases in downstream peak flow rates. Large investments in drainage facilities may be required to prevent flooding resulting from the increased flows.

As a result of escalating costs of drainage works and an increasing awareness of the environmental impacts of runoff, it is apparent that a broader approach to drainage studies is required. For example, control of runoff from new urban developments is receiving increasing acceptance as an environmental management objective. Peak runoff rates after development may be required not to exceed runoff rates under predevelopment conditions. The problem of control of pollution of receiving waters from point and non-point sources is also being closely examined.

A 1973 inquiry into urban drainage practice in Canada revealed that at that time all major municipalities (with the exception of Toronto) employed the Rational formula exclusively in urban drainage planning and design. Within the last few years the Canada-Ontario Urban Drainage Program has sponsored several studies related to the calibration/validation and development of urban runoff models and the advantages of a modelling approach to drainage problems have been recognized by municipalities and other agencies, which have instituted programs of model implementation. The principal models currently used in drainage studies in Canada are STORM, SWMM, WREM, ILLUDAS and computerized unit hydrograph models.

The Water Resources Group of James F. MacLaren Limited has been extensively involved in the model development and verification studies for the Canada-Ontario Urban Drainage Program and also in a considerable number of practical model applications for cities and municipalities across Canada. It is the intent in this paper to review some aspects in the implementation of modelling in drainage planning and design, and to describe the role of models in several recent applications.

MODELLING IN GENERAL

Although this lecture covers only general principles of modelling and general aspects related to modelling objectives, we should be aware that:

- modelling is an art rather than a science,
- the state of this art is rapidly changing,
- there is limited experience with model applications,
- there is a plurality of modelling approaches,

and, therefore,

- principles are more important than formulae.

The implementation of storm water management models represents not only a change in computational sophistication, but also a change in design philosophy. In the traditional approach, "drainage projects" were considered as more or less straightforward design applications. A single person was often responsible for all aspects of a project including hydrologic computations using the Rational formula, sanitary engineering, selection of project alternatives and detailed design.

If models are applied within the framework of "storm water management projects", a study is conducted not by a single person, but by a team whose members have expertise in the different aspects of the project. It is important that the team members be aware not only of the advantages of modelling but also the pitfalls of modelling in general, and urban drainage modelling in particular.

Modelling is always only one of the elements (and often not the most important element) of an analysis designed to assist the decision-maker in the selection of an "optimum" design or policy alternative.

The final decision must be reached by an individual or an agency under given time and budgetary constraints, based on limited information, and within an existing institutional and political environment. Development of a modelling approach must be compatible with all these factors and with the general plan of the analysis.

The modeller is, in general, a member of a study team and he should have a good appreciation of the overall scope of the study. He should also familiarize the other team members with the basic principles and with the limitations of the modelling.

Substitution of traditional methods with modelling have a disadvantage in the potential for increased difficulties in communication between those involved in a study. These difficulties may include resolution of study objectives, and the selection of suitable models.

It should also be remembered that the choice of criteria for comparison of alternatives rests with the decision maker. While the modeller may desire to use the tool which gives the "best prediction", the decision-maker may be more concerned in his selection with the intangible aspects of the project.

Most urban runoff models encountered in the programs of model testing require a significant effort in "debugging" before being rendered fully operational. Additional debugging is often required upon the release of later versions of an existing model. The correction of program errors can be a lengthy and frustrating process and is apt to deter potential users and cause mistrust of models in planners and decision-makers. Some models have proved to be well suited to certain applications but inaccurate in others.

The gap between the state-of-the-art of modelling and the methods used in practical applications is reasonably common to other areas in water resources. One of the causes, as indicated by McPherson [18], is that most of the studies are concerned with the improvement of tools rather than with the solving of problems. Another cause is that many attempts to use new models do not follow some of the basic rules of model implementation discussed by Biswas [19], such as:

1. Start with a simple model and keep it simple.

2. In general, it is not worthwhile to build generalized* all purpose models.
3. The chances of a model being used are greatly advanced if good documentation is available.
4. Modelling and data collection should proceed in parallel.

Various problems associated with implementation of drainage modelling techniques have been discussed by Walesh [16], principally:

1. There is a lack of reliable data concerning the cost of existing models and the costs of associated activities such as data collection and preparation.
2. The additional benefits resulting from model application have rarely been assessed, so the value of modelling has not been established on a cost-benefit basis.
3. Many existing models cannot be practicably used by small consulting firms or small government agencies because of lack of staff members, low probability of repeated model uses, and other factors.

While many studies have been concerned with the description, testing and comparison of models presented in the other papers, it is felt <u>that for a practising engineer, the important decision is whether to use the Rational method or a more sophisticated hydrograph method incorporating, for example, some form of flow routing</u>.

During the course of a project from screening to design, model sophistication, data requirements and computer costs will all increase. The results of each model should lead logically to the next, more sophisticated application and good communications with the decision-makers should ensure a shared objective. The involvement of non-technical planners and decision-makers in regular consultations is essential in this regard.

Our experience indicates that once flow simulation techniques are understood and the potential benefits appreciated, there is a natural

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* Direct conflict with urban runoff philosophy; very difficult to "sell" one-off models!

tendency of planners and decision-makers to become interested in quality simulation as a part of pollution control policy planning.

LIMITATIONS OF DIFFERENT MODELS

The major limitations of the Rational formula have been discussed by many authors:

1. The runoff coefficient does not properly account for antecedent conditions, losses during the rainfall event, and, in general, all the physical factors affecting runoff.
2. The method considers sewer flow routing in a simplistic manner through the time of concentration concept. Non-uniform, unsteady flow in sewers, surcharge and interconnected networks are not accounted for.
3. A complete runoff hydrograph is not developed so the method is unsuitable for the design of drainage systems incorporating storage.

Few models, if any, are completely universal and, therefore, some caution should be exercised when an existing model is applied in a new and untested role. The deficiencies of some well accepted models noted in Table 1 indicate some of the situations in which these models do not perform well. For instance, STORM does not simulate peak flows accurately because of its long time step (one hour) and lack of flow routing routines. SWMM does not accurately simulate hydrographs under surcharged conditions. Conversely, the more sophisticated SWMM-WRE is unsuitable for initial planning applications because of the extensive data preparation and considerable computer time required. While SWMM and WREM have been widely tested and verified on urban watersheds, little evidence of their suitability in predominantly rural situations has been published. Consequently, we have used a computerized unit hydrograph approach in predicting rural runoff flows.

Some confusion may result from these limitations. The designation of STORM as a "planning model" or SWMM as a "design model" may cause a user to be model oriented rather than problem oriented. A dilemma appears to be that as more models are formulated, the chance of each of these being accepted by planners or decision-makers at a municipal level becomes more

TABLE 1. SOME GENERAL MODEL DEFICIENCIES

Model	Comment
STORM	- peak flows not accurate due to 1 hour time step and no flow routing - simplistic storage and treatment routines
SWMM	- antecedent conditions have usually to be assumed - poor simulation of hydrographs in surcharged systems - not well validated for predominantly rural areas - quality model hard to calibrate, somewhat oversophisticated for most applications - receiving water model does not account for pollutant transport by diffusion
SWMM-WRE	- very short time steps required to avoid unstability - extensive data requirements

remote. In the interim, outmoded empirical methods continue to be used for design purposes in some costly storm sewer projects and modelling is not used to its full extent in the examination of alternative solutions to such problems as sewer separation, and the need for upgraded treatment plants. At the present status of model implementation in Canada, further refinement of models and the construction of new models should be carefully weighed against the hidden constraints involved, i.e. additional debugging, time required for familiarization and potential reluctance to implement new and untested models. If currently applied models can be used in a creative and problem oriented manner and be demonstrated to be a means to novel design and economic benefits, then at present these efforts will be more effective in promoting the widespread acceptance of modelling than further model refinement. Deficiencies of one model can be avoided by the use of model packages as described in the following example.

An Example of a Model Package for Flood Control in an Urbanized Watershed

A generalized representation of a model package envisaged in the study of flood control alternatives for Etobicoke and Mimico Creeks by James F. MacLaren Limited has four main components, namely:

i) An event screening and simulation submodel,

ii) A hydrologic and routing submodel,

iii) A backwater submodel,

iv) A submodel for evaluation of various water quality parameters in the streams,

v) An economic and assessment submodel.

All of the submodels which form the basis of the modelling package are readily available, non-proprietory models.

Event screening and simulation submodel - The function of this submodel is to prepare and screen meteorological data in order to define design events and establish antecedent conditions. Two existing models - DAM and STORM are used for this function. A Data Analysis Model (DAM) is used to prepare and analyse the record of meteorological conditions (hourly precipitation and temperatures) measured at the Toronto International Airport First Order Meteorological Station. The Data Analysis Model processes this meteorological information, fills in missing data where possible, and prints out a summary for major events, including data required for assessing antecedent conditions. The processed data are automatically punched on computer cards in the correct format to be used in the STORM model simulations.

The STORM model is a relatively simple continuous simulation model which was developed by the U.S. Army Corps of Engineers. The model requires minimum data input - (hourly precipitation and temperature) and a minimum calibration effort. It is capable of simulating snow accumulation and melt, peak flows and flow volumes on a continuous basis, water quality parameters including BOD, suspended solids, total coliform, nutrients and surface erosion (using the universal soil loss equation). The model also accounts for antecedent conditions by an evaporative loss factor. Therefore, in addition to preliminary water quality simulations, the DAM-STORM model combination is used for a continuous simulation of peak flows and runoff volumes for the Etobicoke and Mimico Creek watersheds to assess antecedent conditions of the selected design events. High flow volumes for lower intensity, longer duration events, e.g. snowmelt or rain on snow conditions, can be a more critical factor than peak flow when considering flood protection to be provided by a proposed flood control

reservoir. These design events, with associated frequencies and real antecedent conditions would then be simulated in more detail and with a higher degree of accuracy by using the one-event hydrologic and routing submodel.

Hydrologic and routing submodel - Once the design meteorological and antecedent conditions have been identified for the required flow frequencies (e.g. 5, 10, 25, 50 and 100 year floods) it would be possible to carry out detailed hydrologic simulations using the one-event hydrologic and routing submodel. We have available two options for this submodel - Option A utilizes the Unitgraph HYMO flood flow prediction technique. This method is used for flow simulation and channel and reservoir routing for predominantly rural and semi-urbanized watersheds. Option B utilizes a lumped SWMM model for small highly urbanized sub-watersheds and where detailed water quality and/or snowmelt simulations are required. When used only for rainfall-flow calculations, both of these models have similar input data requirements and have comparable computer costs.

We utilize the HYMO option for the flood calculations, since the SWMM model has not yet been adequately tested in Canada for rural watersheds in excess of five square miles. However, on the basis of current research activities in the United States, the SWMM model will soon become available both as a long-term simulation model and as a proven flood prediction model for rural watersheds.

Either model requires initial calibration prior to simulating floods to define the flow frequency relationships which are used in the damage calculations. In addition to the calibration of the HYMO runoff parameters, it is essential that the proper antecedent conditions be determined and utilized for the selected design events. Calibration and determination of antecedent conditions are still required to develop sound stage-frequency relationships at flood prone locations.

Backwater submodel - The HEC-2 Backwater model is used in order to derive the stage-frequency relationships at flood prone locations.

Economic and assessment model - Once flood prone areas have been determined, a number of possible flood control alternatives and constraints are identified. Preliminary screening of these alternatives is then carried out through an initial scoring system. Capital costs for the remaining alternatives are then estimated.

Total average annual damages are either manually computed for flood prone locations or by using an optional model - the HEC-ADD program.

Impact matrices are also used to compare alternatives. These procedures do not attempt to quantify non-commensurables in any economic sense but do attempt to include their presence in the overall evaluation procedures. A matrix is constructed to illustrate the relative effects of alternative projects on various social/aesthetic/environmental characteristics. The method we use is a simplification of the Goals Achievement Matrix which has been implemented in Colorado.

EXAMPLES OF APPLICATION OF URBAN RUNOFF MODELS

Models are applied for both large and small drainage studies. An example in the first category is the Master Drainage Plan for the Thornhill-Vaughan Community. An interim community plan has been developed to accommodate a future population of about 80,000 in a 4,500 acre area of the Town of Vaughan. At present, the area is predominantly agricultural and runoff is carried through watercourses to the west and east branches of the Don River. A master drainage plan was developed to provide for orderly implementation of storm drainage systems to service the new community. The plan was required to meet Ministry of Environment runoff criteria, principally:

i) runoff control to limit peak runoff rates to the major receiving streams to pre-development levels, and

ii) no degradation of water quality, including sediment effects during construction periods.

The main features of the drainage concept in this regard are:

i) Natural watercourses are to be retained as open channels wherever possible.

ii) Storage ponds will limit runoff rates to the Don River from a large part of the developed area.

iii) These ponds will provide some quality control and will retain sediment washed off during construction. Temporary retention basins were also recommended for sediment control

The SWMM was applied for estimation of post-development runoff hydrographs from design storms for the subcatchments of the study area, and the required storage areas were determined. When the community plan has been finalized, the SWMM will be used for prediction of runoff characteristics, for sizing of drainage system components, e.g. storm sewers and storage ponds, and for assessment of management alternatives such as surface detention storage.

An example in the second category is the Prince Road Storm Relief Sewer Study in the City of Windsor. The 360 acre Prince Road drainage area of the City of Windsor is served largely by a system of combined lateral and trunk sewers. Considerable flooding of basements has been experienced in recent years. An analysis using the WRE model indicated that almost all lateral sewers are of insufficient capacity to contain the five-year design storm. Furthermore, since many of the existing sewers were built close to the basements, there is very little opportunity to employ cross-connections and surcharging to distribute flows throughout the system. Complete separation of the laterals was recommended with the construction of a new trunk storm sewer. The performance of the proposed trunk sewer was simulated for the five-year storm using the WRE model. It was found that some surcharge in the trunk was acceptable and that this surcharge (generally less than 5 feet) would provide significant reductions in pipe sizes over a design based on free-surface sewer flow. The modelling was carried out for two alternative trunk routes and preliminary costs for these routes were included in the final report to the City of Windsor.

Two typical examples of model applications for studies of pollution abatement are:

1) <u>Combined Sewer Overflows in the City of Winnipeg</u>

The City Waterworks and Waste Disposal Division measured flow and quality in a number of combined sewer systems during summer storms in the period 1969-71. These measurements indicated that in the first stages of storm runoff, pollutant concentrations in the combined sewage could exceed those found in the dry weather flow because of the scour of solids deposited in the trunk combined sewers in dry weather. This study

used the City's measurements to calibrate STORM in order to provide an assessment of the magnitude of pollution resulting from combined sewer overflows to the Red and Assiniboine Rivers. The overflows from 41 combined sewer districts were simulated over five years and the areas contributing most heavily to river pollution were identified. Detailed analysis of the first flush of pollutants in the overflow was possible using the SWMM model. Various policies to alleviate overflow pollution were investigated, including separation, increased interception, storage and overflow treatment. The study concluded that separation is not usually the most effective abatement measure for an existing combined system; rather a system of total management involving storage, overflow treatment and nonstructural controls such as sewer flushing is both more effective and more economic.

2) Feasibility of Combined Sewer Overflow Pollution Control in the City of Edmonton

A previous study had demonstrated that during frequently occurring low intensity rainfall events, there was excess capacity in the City's main trunk combined sewer system. This study was carried out to determine the feasibility of controlling surcharge and storage in the deep tunnel system in order to reduce the amount of combined sewage overflowing to the North Saskatchewan River and to partly equalize flows to the treatment plant. The number of overflows from the combined system was simulated over one year using the STORM model which was calibrated against overflow measurements made by the City in 1975. The modelling indicated that relatively small volumes of storage would be quite effective in reducing overflows and overflow pollution. Subsequently, the WRE model was used to assess the effectiveness of employing a variable height regulator gate to control storage in the sewer system. Automatic regulators in other cities were investigated and a program for the implementation of computer controlled variable regulator gates at locations throughout the combined sewer system was developed. The drainage area to be controlled will be about 11,000 acres and the preliminary estimate of the capital cost of the project is $4-5 million. During the project, the City recorded storms across the City by means of a newly installed network of recording rain gauges. Part of the implementation program is

to extend this data acquisition effort to include the sensing of water levels at key locations in the system with a centralized computer data processor being installed in City Hall, Edmonton.

An example of an unconventional use of WREM is the hydraulic analysis of sanitary sewers in the St. Boniface area of Winnipeg. Basement flooding resulting from sanitary sewer backup has been repeatedly experienced in the 1800-acre St. Boniface area of Winnipeg. Previous studies by the City had indicated that this flooding was caused primarily by significant inflows of rainwater through house foundation drains which are connected to the separate sanitary sewers. The objective of this study was to analyze the hydraulics of the sanitary sewer system in this area and to evaluate alternatives for alleviation of basement flooding problems. The WRE model was selected as the appropriate analysis tool, particularly because the model handles surcharge and looped networks which were important considerations for this area. Calibration of the model was achieved by varying the extraneous flow rate until the model reproduced the historical flooding patterns. The extraneous flow rate established for most areas was 3 gpm/house, which is considerably greater than the current design allowance made by the City of 1 gpm/house. The model analysis indicated that the surcharging and flooding resulted from hydraulic inadequacies in the collector lines causing back-up into the laterals (less than 12 inches). Various relief alternatives were proposed. The performance of the relief alternatives in reducing basement flooding and sewer surcharging was simulated with the model. Cross-connections recently installed by the City were found to provide adequate relief in some areas and the additional sewer relief requirements were determined in the other areas. Recommended relief alternatives with costs varying from $560,000 to $682,000 were presented in the final report.

Models were used to aid in the environmental study of sedimentation and water quality at the Humber River mouth. The purpose of this study was to assess the existing water quality in the Humber Bay area of the Toronto waterfront and to investigate measures to ensure acceptable water quality in the vicinity of the Humber mouth where landfill is being used to create nearshore island parks. In addition to water quality aspects, the study was directed towards obtaining a means to control sedimentation

around the Humber River outlet. Hydraulic and aerodynamic scale models were constructed for the investigation of sedimentation processes and the testing of different remedial measures led to a recommendation for the construction of a hydraulic jetty-type structure at the river outlet. The aerodynamic model was also used to examine the best shapes for new offshore islands and to test the diversion of the nearby Mimico Creek in order to improve flushing in the major artificial embayment. Water quality along the lakefront appeared to be related to the intermittent discharges from combined sewer overflows and storm sewers. The Receiving Water submodel in SWMM was used to simulate the dispersion of these discharges in Humber Bay. The modelling helped identify potential future problem areas associated with proposed island developments and some options for storage and treatment of certain sewer overflows were considered.

ECONOMICS OF MODELLING

The traditional approach to analysis of overloaded sewer systems has been to compare the design flows estimated by the Rational method with the full-flow capacities of existing pipes. The pipes which are under surcharge are identified, but it is not possible to determine whether or not the degree of surcharge is acceptable. With analysis methods such as SWMM-WRE, water levels are determined throughout the system. These levels are then compared with safe levels, e.g. basement elevations in a combined system, to identify the locations of existing system inadequacies. The advantage of this information is that it is possible to identify priorities in the design of relief sewers, mainly in defining the staging of investments between laterals and trunk sewers.

The capability of SWMM-WRE to account for cross-connections, which redistribute surcharge, can be utilized to design economic relief systems based on inter-connecting sewers or cut-off sewers. This approach yields a considerable cost saving over traditional methods. The allowance of a small surcharge represents a management technique to better utilize in-line storage so that substantial reductions in pipe size are possible.

Other types of storage may also have substantial economic benefits. For example, temporary ponding on roofs and parking lots of shopping centres can greatly reduce the peak value of the outflow hydrograph. The reduced outflow may satisfy the maximum allowable inlet requirement for an existing drainage system or can provide size reductions for a new system. The incorporation of storage ponds in drainage systems for new subdivisions, can have aesthetic and environmental benefits as well as economic advantages. For this particular situation, the peak flow for a development of 61 acres was reduced from 220 cfs to 20 cfs. Similar results could be obtained by a holding tank. The volume of storage determined by SWMM was 20 percent smaller than that determined by an approximate method. Since the development of runoff hydrographs is required for evaluation of storage alternatives, the models have definite advantages for these applications.

In the area of master drainage planning, criteria are being developed to limit the environmental impacts of drainage. These criteria generally require that the runoff increase resulting from urbanization be minimized and that the pollution from urban runoff be controlled. Comparison of runoff hydrographs before and after development and simulation of pollutant washoff will be required to provide the necessary information. Clearly, this type of study is possible only with the use of hydrologic models. Modelling was used in a master drainage study of a 4,500 acre urbanizing area upstream of Metropolitan Toronto. Studies for a sub-watershed led to the recommendation of two storage ponds, with total area of about 10 acres, which will reduce the post-development runoff rates from a large part of the area of 2,100 cfs for a 25-year storm to pre-development rates of 630 cfs. Drainage models of new areas under development may also be applied and refined as part of the total urban planning process to compare the effects of different land use alternatives.

The capability of models to reproduce routing conditions is best utilized in simulation of flows in the trunk sewers and interceptors of large drainage areas. In a recent application in Canada, it was possible to model the flows in the major lines of a combined sewer system for 11,000 acres, accounting for significant surcharge, interconnections, diversion structures and overflows. The Rational method was an unsuitable

tool for analysis of this complex system and in some locations, the method would lead to order-of-magnitude errors in flow estimation. The modelling study led to significant savings by identification of problem areas and recommendations for flooding control by relief of lateral sewers and pollution abatement by real-time control of trunk and interceptor sewers.

An important problem in the selection of new models versus traditional techniques is the cost of modelling. In a drainage study utilizing models, many activities such as data collection, development of alternatives and report writing generally cost little more than in a study where the analysis is based on the Rational method. The following table gives coarse estimates of study costs (both the total cost and the cost of modelling) for different types of drainage studies:

	Study cost ($/Acre)	
	Total	Modelling
1. Master drainage plan for small community (5000 persons)	18-22	5-8
2. Preliminary master drainage plan for large new development (4000-5000 acres)	4-6	2-3
3. Detailed analysis of relief sewers for sewer districts (200-1000 acres)	20-35	6-10
4. General analysis of trunk sewers for a large city (10,000 acres)	4-6	2-3

If an average capital cost of $5,000 per acre is assumed for storm drainage, the above estimates indicate that the cost of modelling is generally less than 0.2 percent of the capital cost. The examples presented above demonstrate that some storm water management alternatives may provide significant reductions in design flows. Experience in a range of studies has indicated that the reduced design flows lead to significant savings in capital costs, so that the return from modelling is substantial. In certain cases when the modelling costs are higher than shown above, e.g. detailed analysis of several alternatives for a small drainage area, the extra costs are justified through increased returns.

The above cost estimates are intended as guidelines based on previous experience in modelling studies. They assume staff expertise, computer accessibility and other facilities that might be present only in specialized groups. When an organization is investigating implementation of models, recovery of the front-end costs over a number of future projects must be considered.

The cost of training staff is related to the object of training. Most potential users are interested in a basic understanding of modelling principles, selection of models, and monitoring of studies performed by specialized groups such as consultants. Seminars organized by the Canadian Urban Drainage Subcommittee and the U.S. Environmental Protection Agency have covered most aspects of modelling including numerical examples in three to five days. Experience with municipalities such as Winnipeg and Edmonton has shown that staff engineers can conduct independent modelling studies after working jointly with an experienced team for several months.

It seems, therefore, that the total cost of model implementation in urban drainage need not be excessive.

CONCLUSION

Comparison of urban runoff models with the Rational method must be based not only on accuracy of flow simulation but also on the scope of drainage studies possible using the different methods. For example, if the Rational method is used in the drainage system design for a new development, the designer is limited to a traditional concept of pipes sized for free-surface flow and rapid removal of runoff without consideration of downstream runoff increases and environmental effects. However, if the design is to be oriented towards management of runoff (considering retardation, storage, etc.) in order to develop a drainage system which is both economical and environmentally sound, modelling is required to assist the designer in determining the best solution.

While recent activities by different agencies, municipalities and consultants have led to implementation of runoff models as tools for practical solution of urban drainage problems, further efforts are required to improve the availability and effectiveness of modelling techniques at all levels of engineering practice. Efforts to remove the

non-technical constraints to further model implementation should include identification and documentation of the benefits and costs of modelling, the requirements for staff training and organization of technical assistance.

The goal of replacement of outmoded empirical design formulae currently widely used in Canadian urban drainage planning and design by more accurate and reliable methodologies will be best served by demonstration projects indicating practical advantages of models.

The experience in a number of research and practical urban drainage and pollution control studies confirms that modelling is a dynamic process. No single model or unique pattern of application can be recommended. Best results are likely to be achieved with a series of interfaced models applied within proven limitations.

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TREATMENT TECHNOLOGY FOR URBAN RUNOFF

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SOURCES OF TREATMENT TECHNOLOGY

Control or treatment of storm water induced pollution has not received a high priority in most countries, even those with an advanced level of sewage treatment. Currently, interest, research and development activity on the subject is greatest in the United States with growing interest in some regions of Canada, including Ontario. Interest in the United States is largely attributable to the efforts of the EPA Storm and Combined Sewer Research Development and Demonstration Program.

In 1964, the U.S. Public Health Service completed a first federal and nationwide appraisal of the problem [1]. In 1965, federal funding was made available to states or municipalities for use in projects which show potential for demonstrating new or improved methods of controlling untreated overflows from sewers into natural waters.

In 1970, an EPA sponsored study recommended the discontinuance of sewer separation, in favour of developing pollution abatement programs related to the specific needs of individual combined and separate sewered areas.

Alternative approaches were encouraged for several reasons including the high cost and long time span for implementing sewer separation and associated community disruption. Additionally, it was becoming apparent that separation in itself would not necessarily solve water quality problems associated with storm flows.

Over 140 projects have been carried out with funding from the demonstration grant program. As a result of this activity, new technology is now available to those engaged in the planning and construction of remedial works for the abatement of pollution from combined sewer overflow. The technology covers a wide spectrum of measures in the areas of source controls, collection system controls, storage and treatment. From the many treatment-oriented projects which have been funded, some viable

processes have resulted which were conceived and designed specifically for the highly variable wet weather flows in combined sewer systems.

The EPA program has covered many areas relating to the reduction of pollution from surface runoff in separate sewered areas including studies or demonstrations in the areas of source controls, erosion controls and the beneficial use of storm water.

Distinctive treatment technology for surface runoff has not been emphasized to date. A recently initiated project [2] will examine the application of a number of devices to the removal of fine particles from surface runoff. To the present, practical applications in treatment of surface runoff in the United States are represented by the use of retention-sedimentation basins of a type first used for erosion controls.

The United Kingdom has made some contribution to the development of treatment technology for combined sewer overflow. Considerable investigation of regulator structures was carried out in an effort to minimize the discharge of suspended solids in combined sewer overflow. These studies led to the development of a vortex separator and spiral flow regulator [3]. The Swirl concentrator and Helical Bend Separator developed by the American Public Works Association are closely related to these devices. In each case, the original concept of the UK device has been retained but extensive hydraulic and other studies have been carried out to optimize the design.

In the UK, and several other European countries, use has long been made of storm tanks to minimize combined sewer overflow. In the UK, this practice has been established for more than 65 years [4]. In a sense, this is the earliest and simplest technology for abating combined sewer overflow.

Drainage system design in the new city of Milton Keynes includes extensive measures to limit the discharge to natural waters of the oil expected to be present in surface runoff from industrial areas [4]. Oil 'interceptors' on storm sewers will include both API and tilted place separators - probably the first large-scale application of these devices to municipal storm water.

To this point, Canada has not been a source of treatment technology for surface runoff or combined sewer overflow. In Ontario,

the Urban Drainage Subcommittee of the Canada-Ontario Agreement has funded only a relatively small number of treatment technology development or demonstration programs, partly because of the breadth of the existing technology base applicable to combined sewer overflow.

If Ontario, or other provinces, are to control pollution from storm water in the near future, they will be able to do so largely because research and development in other countries has provided some basic technology.

FULL SCALE TREATMENT TECHNOLOGY FOR COMBINED SEWER OVERFLOW

Current State-of-the-Art

Chapter 5 of the Urban Drainage manual [5] contains descriptions and representative costs of the processes which have been applied at large scale for the treatment of combined sewer overflow. Table 1 restates some of these.

TABLE 1. SOME PROCESSES DEMONSTRATED AT LARGE SCALE FOR TREATMENT OF COMBINED SEWER OVERFLOW

PHYSICAL - (W and W/O Chemicals)
- Fine Screening
- Microstraining
- Retention-Sedimentation Basins
- Dissolved Air Floatation
- Swirl Concentrator

BIOLOGICAL
- Contact Stabilization
- Trickling Filters
- Aerated Lagoons

The selection shown includes a wide variety of treatment processes all of which are suited to handling the highly variable flows and quality of combined sewer overflow. The processes listed have widely different "representative performances". The upper limits of efficiency are reached by the contact stabilization process whose representative performance is 75-88% BOD_5 removal and 90% SS removal.

Most of the processes shown were first applied at large scale under the EPA demonstration program. Good documentation describing the processes and their performance exists.

Rather than further describing the available technology, it seems more appropriate to discuss some treatment applications at large scale in Canada.

Canadian Experience in Treatment of Combined Sewer Overflow

To date, experience has been very limited. The full scale installations which are currently operational are basically retention storage/sedimentation facilities. Of three such facilities in operation at the present time, only the one in Halifax has received an extensive study of its performance [6]. The most recently constructed facility of this type is at Welland, Ontario.

A full scale evaluation of high rate fine screening was carried out at the Belleville WPCP with funding from the Canada-Ontario Research Agreement in 1974 and 1975. The Halifax and Welland retention storage/ sedimentation facilities and the Belleville screening project will be described.

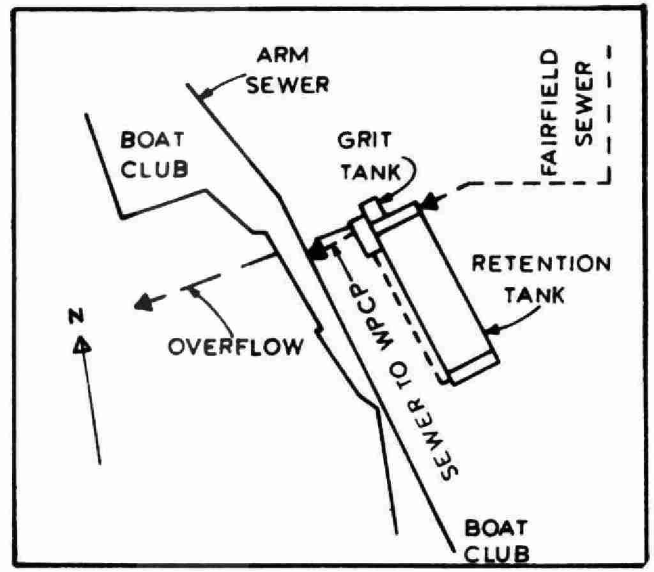
Retention storage/sedimentation - Halifax, Nova Scotia

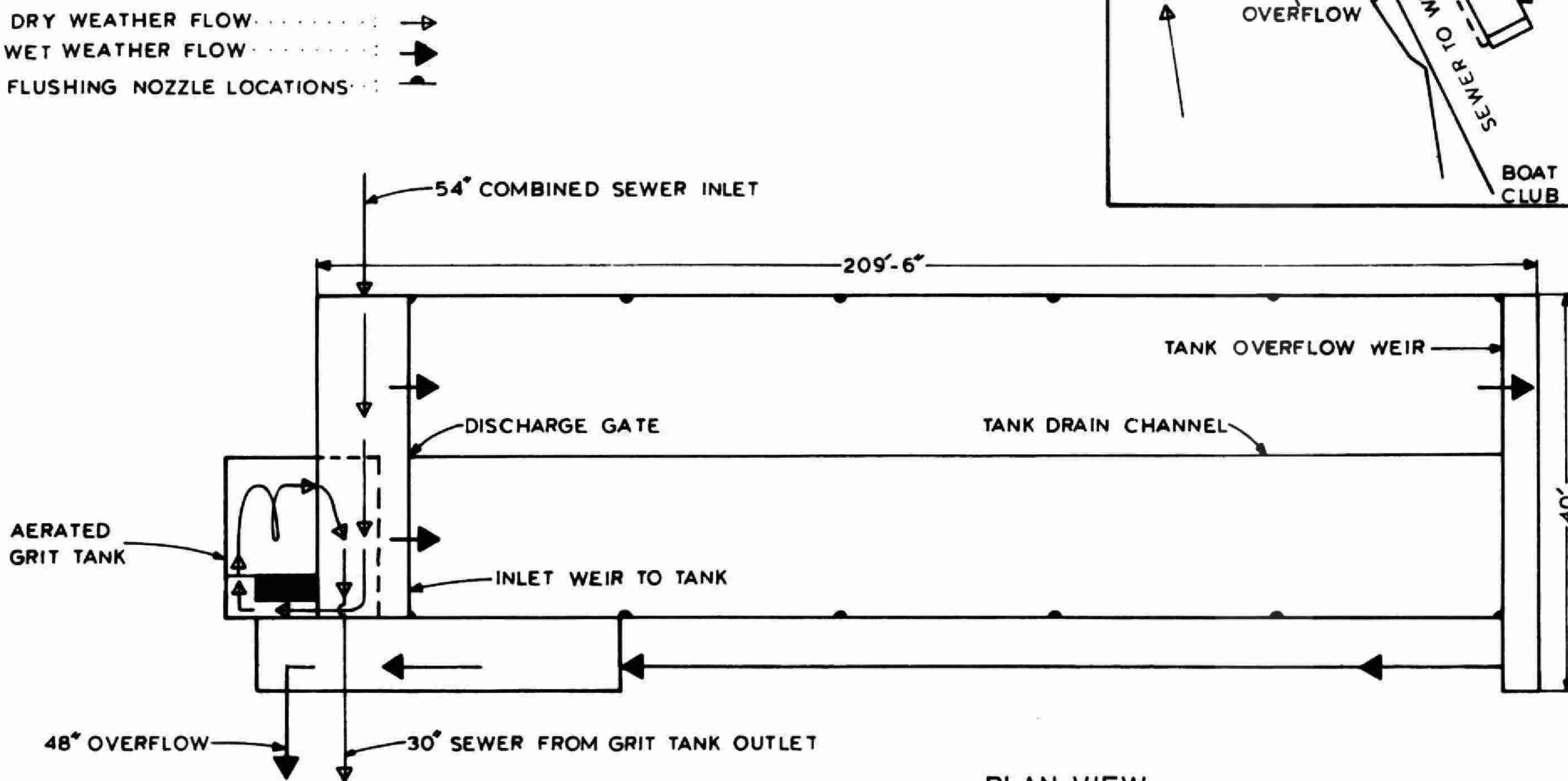
Combined sewer overflows from a 168-acre combined sewage system posed a problem for the City of Halifax by adversely affecting the recreational uses of the waters of the North West Arm to the inlet of Halifax Harbour. Conventional abatement measures such as complete separation, or the construction of an enlarged interceptor, were rejected on the basis of excessive costs [6].

Consequently, the use of a retention tank was considered to capture some portion of the storm flows in excess of the interceptor capacity, with subsequent discharge to the interceptor following the storm event.

The tank is 200 ft long x 40 ft wide x 15 feet deep, is covered and has a volume of 144,000 ft^3. It cost $420,000 to construct in 1966. Retention tank operation is illustrated with the aid of Figure 1 which

FIGURE 1 LOCATION AND ARRANGEMENT OF HALIFAX COMBINED SEWER RETENTION TANK, AND CONNECTING SEWERS





PLAN VIEW

also shows the placing of the retention tank relative to the interceptor and the overflow point.

Dry weather flow entering the tank inlet channel passes through an aerated grit tank and on to the interceptor. During storm conditions when flow in the interceptor reaches a maximum allowable level, flow through the grit tank is hydraulically self-limiting, resulting in flows to the retention tank. Chlorination starts and continues in proportion to inflow as long as the rate of inflow exceeds outflow to the interceptor. Coarse bar screens retain gross particulate matter at the entry to the tank. Any tank overflow which occurs is discharged to the North West Arm. When flow rates in the interceptor drop, the retention tank is emptied back via the inlet channel and grit tank.

When the tank has emptied it is flushed by nozzles located at intervals along the sides of the tank at floor level. The roof of the tank is constructed such that when the tank is full the roof beams act as skimmers and prevent floating materials from discharging to the receiving water.

The tank provides some treatment (by sedimentation and disinfection) of the combined sewage that is discharged to the receiving water if the tank should fill. Chlorine addition is activated at a tank depth of 5 ft. The tank size was selected on the basis of 15 minutes detention at the peak design flow of 150 cfs - a time judged adequate for disinfection.

An evaluation of tank performance was carried out between June and November, 1970 [6]. The study revealed that in the absence of the tank, rainfalls in excess of 0.05 inches would load the WPCP to capacity resulting in overflows. Rainfalls in excess of about 0.9 inches produced overflows of the tank itself during the study.

From a frequency analysis of 20 years of daily rainfall records, it was estimated that the tank would eliminate 90% of all overflows. During the period of the study, the tank prevented discharge of about 2/3 of the potential overflows. The tank also removed between 30 to 70% suspended solids from overflows for detention times of 0.5 hrs to 3 hrs. Since the tank went into operation the quality of the receiving water was noted as having improved significantly.

Figure 2 is a summary of the volume and fate of wet weather flows from the combined sewers during the study period. It also shows that the bulk of the tank overflow volume was produced from four major storm events. No disinfection data was available from the study period due to equipment problems.

Welland, Ontario - Retention basin for combined sewer overflow

In 1972, the City of Welland completed construction of a 5 acre, off-line holding basin for combined sewage with a capacity of 10 million gallons at a cost of $400,000.

Some measure to deal with overflows was necessary since construction of the new Welland Canal would cut off the outlet of Lyons Creek into which all overflows had previously discharged. The retention basin was the lowest cost alternative available.

The basin provides retention for wet weather flows, including snow melt, in excess of interceptor capacity. The combined sewage is returned to the WPCP at periods of low flow. Tank drainage to date has usually commenced during days, but continues at night unless rain is forecast. The limiting factor on drainage rate is the WPCP capacity - returned flow receives full primary and secondary treatment.

Tank discharge is by gravity flow through a 36" diameter sewer to a pumping station and outflow rate is controlled by adjusting a motorized gate remotely from the WPCP or manually at the basin itself. Discharge rate from the tank is measured through a Parshall flume equipped with a daily totalizer. Any overflow from the basin discharges via an open ditch to the Welland Canal without further treatment. Overflow volume is not measured. The relative locations of retention basin, pumping station, Welland Canal and interceptor sewer are shown in Figure 3.

The basin is of irregular shape with overall bottom dimensions of 75' x 250' x 400' x 500' with a maximum working level of 14 ft and side walls with a slope of about 1 in 5.

The basin has two cells, #1 and #2, which are in series. Cell #1 is concrete lined; cell #2 is sodded. There is a baffle wall between cells #1 and #2 designed to retain floatables and to contain small overflows in cell #1. The bulk of the solids entering the tank settle in

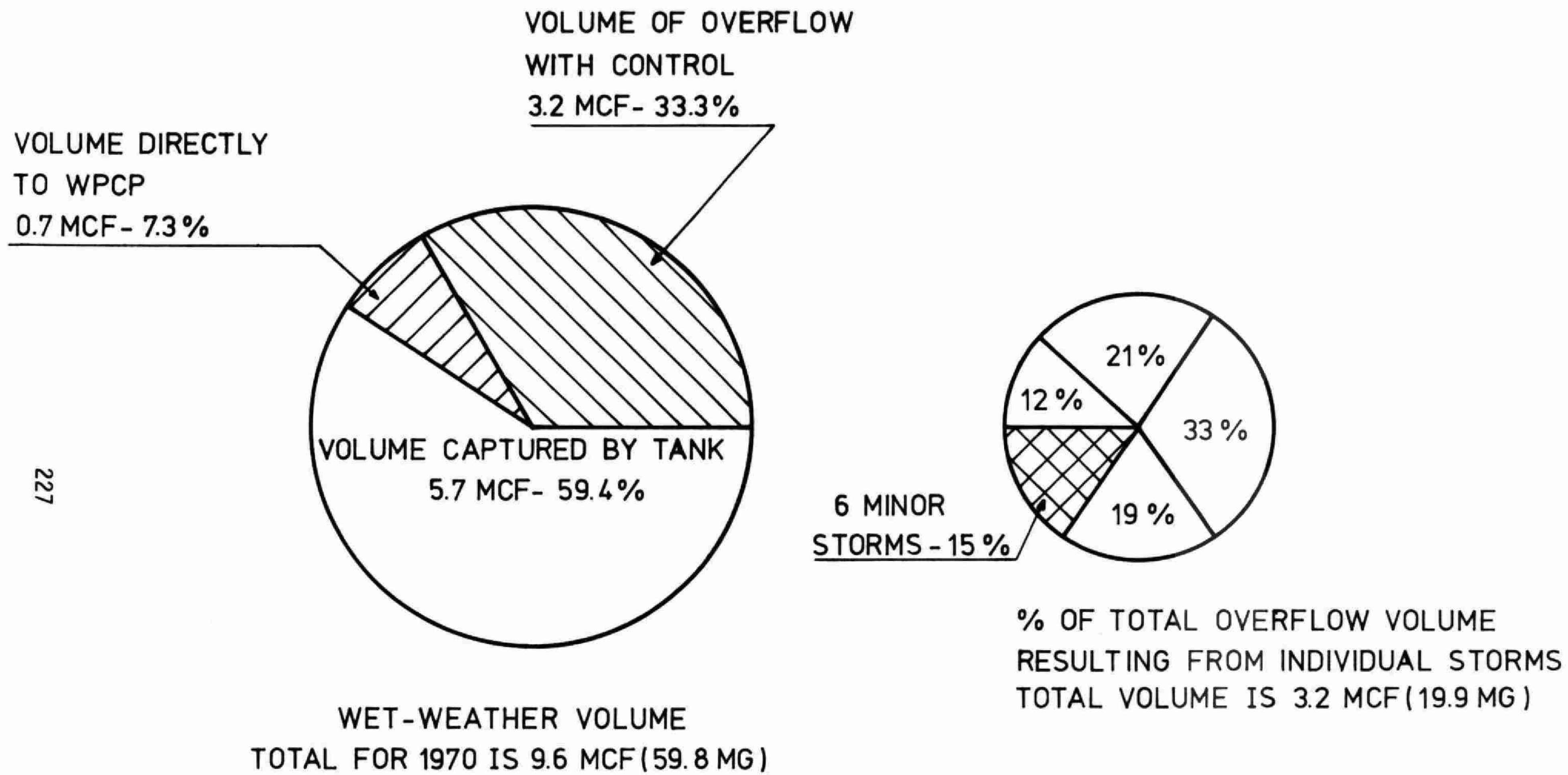


FIGURE: 2 HALIFAX STORM TANK • VOLUME AND FATE OF WET-WEATHER FLOWS • JUN.-NOV. 1970

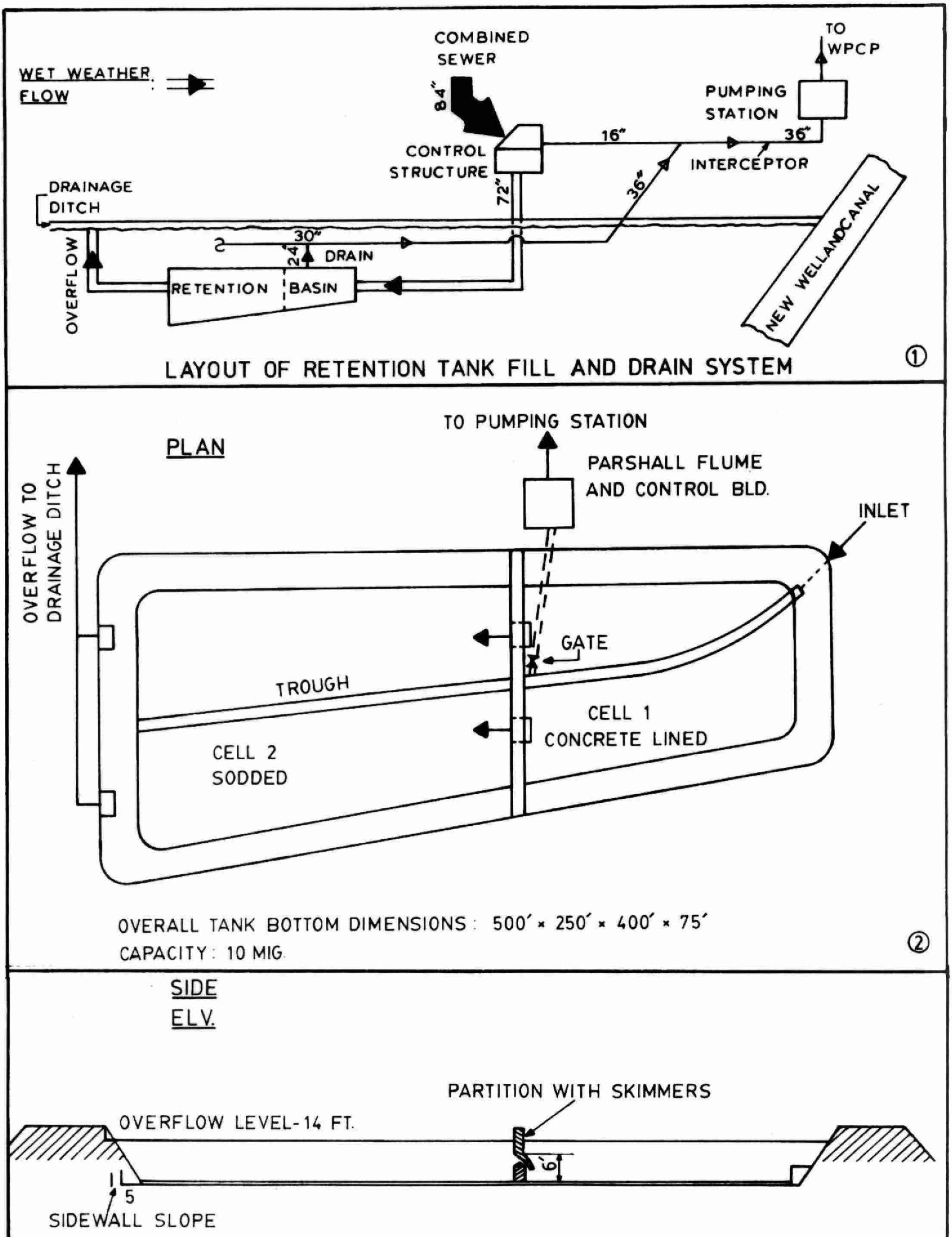


FIGURE: 3 LAYOUT OF WELLAND CSO RETENTION BASIN

cell #1. Cell #1 is cleaned after draining by flushing settled solids to a drainage trough with the aid of a truck-mounted water cannon. Although the basin is located close to housing, no odour complaints have been received to date.

The basin originally served a 450-acre (95% residential, 5% industrial) combined sewer area which is now reduced to about 338 acres due to ongoing sewer separation. Population of this area is about 4000. Volume captured during 1976 was in the order of 35 million gallons corresponding to 4.5 inches of precipitation or about 12% of the estimated flow from this area. Tank overflow used to occur two or three times per year but with the reduced service area, the frequency of overflow is now further reduced. Overflow is not measured.

The percentage of total annual volume captured in each month of 1976 is presented in Figure 4 together with precipitation data. The precipitation data is from a rain gauge at the Welland WPCP. It is apparent that potential overflows are being captured in all seasons, and that there is no simple relationship between monthly precipitation and volume captured. No quality data relating to tank contents or overflows is available.

High-rate screening study - Belleville, Ontario

Four fine mesh, high-rate screening devices were evaluated on storm-induced flows of combined sewage at the Belleville, Ontario WPCP. Sewage flows to this plant are subject to substantial infiltration, dilution and flow peaking during wet weather periods [7]. The primary objectives of the study were to determine the feasibility, cost and practicability of high rate fine screening of storm flows.

The screens comprised a centrifugal wastewater concentrator (CWC) with 105 micron screen apertures, two stationary inclined screens (DSM and Hydrasieve) having 305 and 762 micron apertures, respectively, and a rotating horizontal drum screen (Rotostrainer) with 500 micron apertures.

The CWC unit was the largest, screening being 60 inches in diameter; the inclined screens were 24" and 72" wide, respectively, and the rotary drum screen was a 25" diameter unit. These types of screen have all been described elsewhere in the literature [1, 8] and will not be described in detail in this paper. Figures 5, 6, 7 and 8 are schematics

TOTAL VOLUME CAPTURED BY BASIN IN 1976 - 34.535 MG OR 4.5 INCHES OF PRECIPITATION

TOTAL ANNUAL PRECIPITATION IN 1976 - 34.5 INCHES

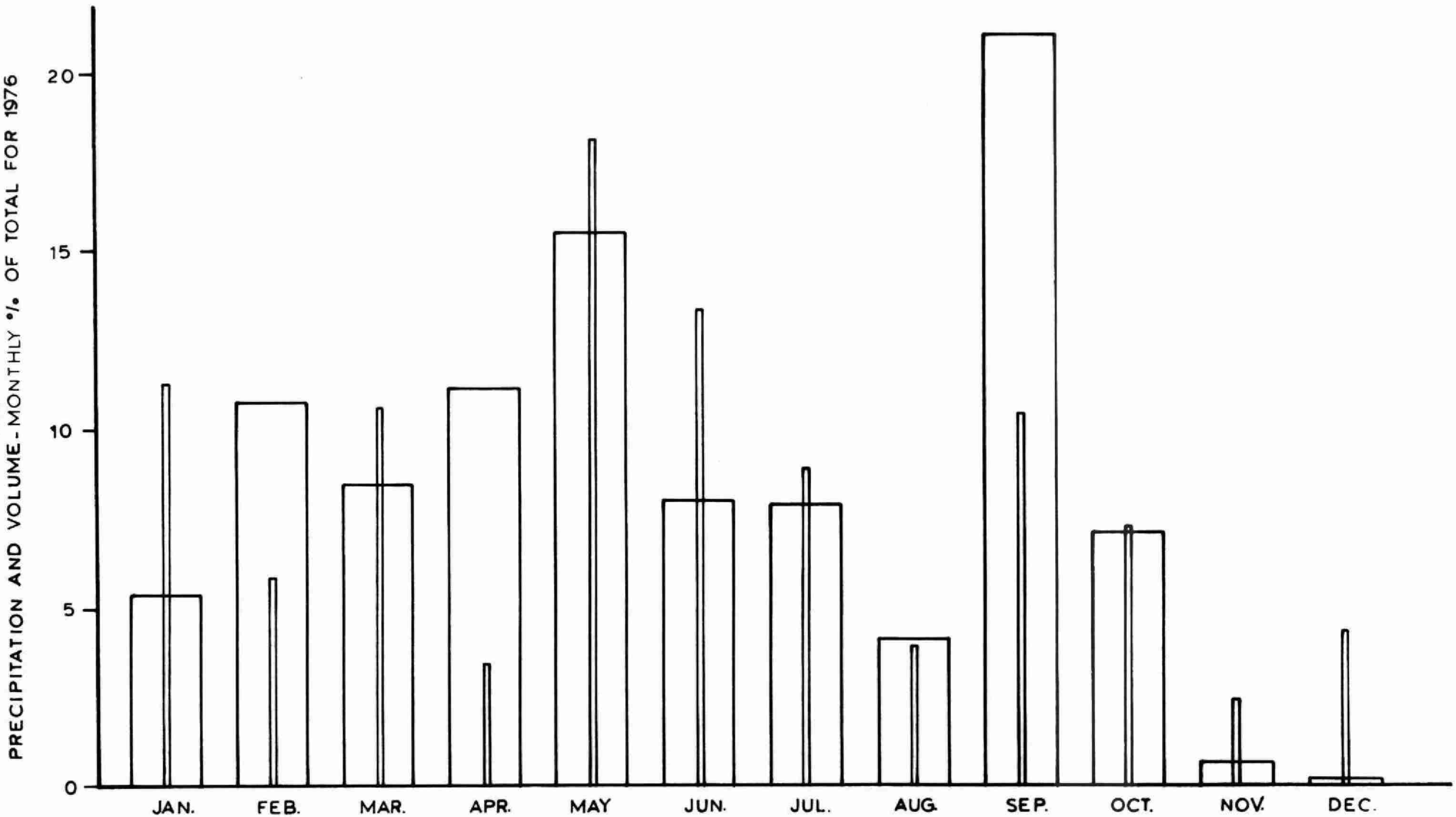


FIGURE :4 PRECIPITATION AND VOLUME CAPTURED - 1976
WELLAND RETENTION BASIN

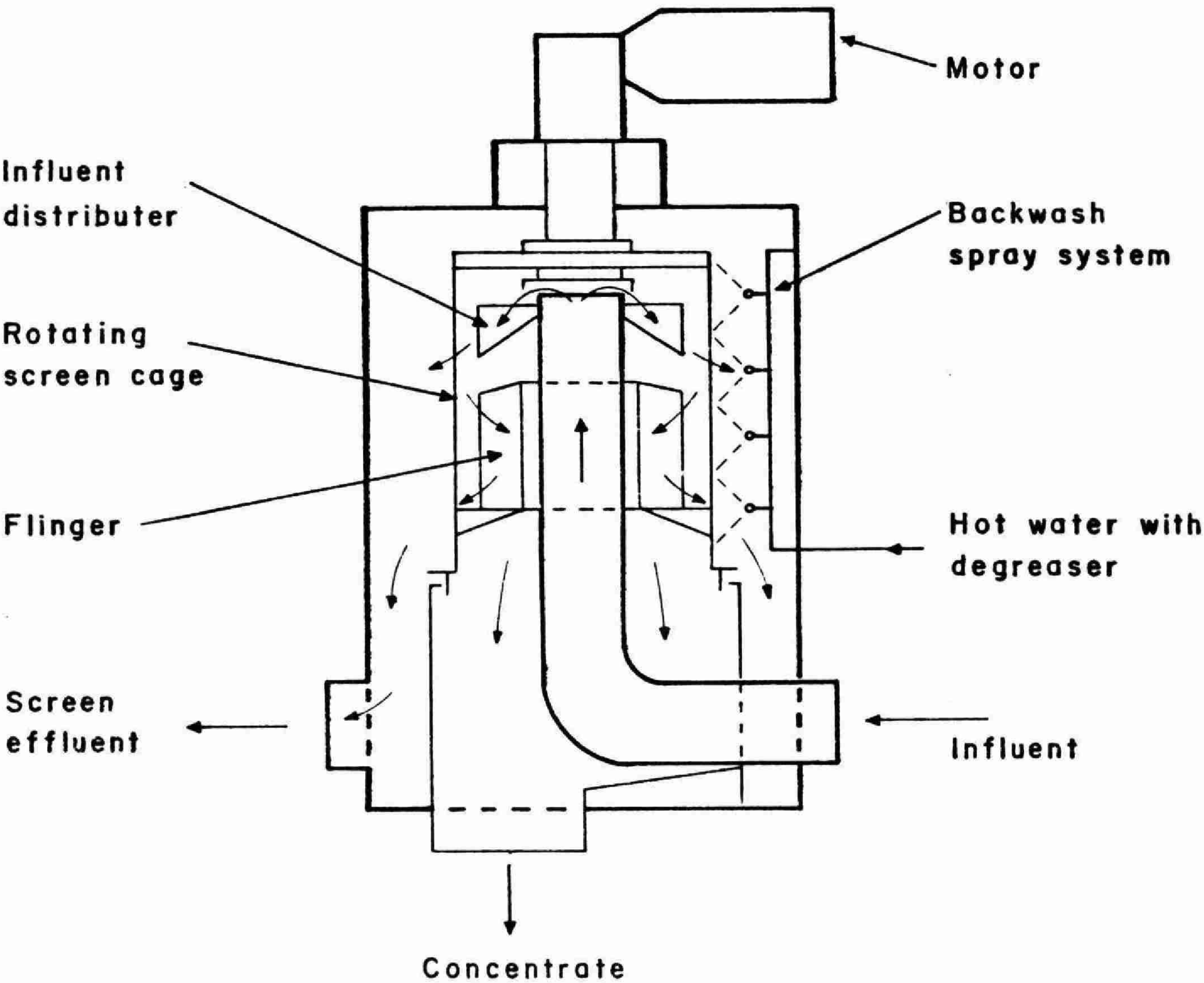


FIGURE: 5 SCHEMATIC OF CENTRIFUGAL WASTEWATER CONCENTRATOR.

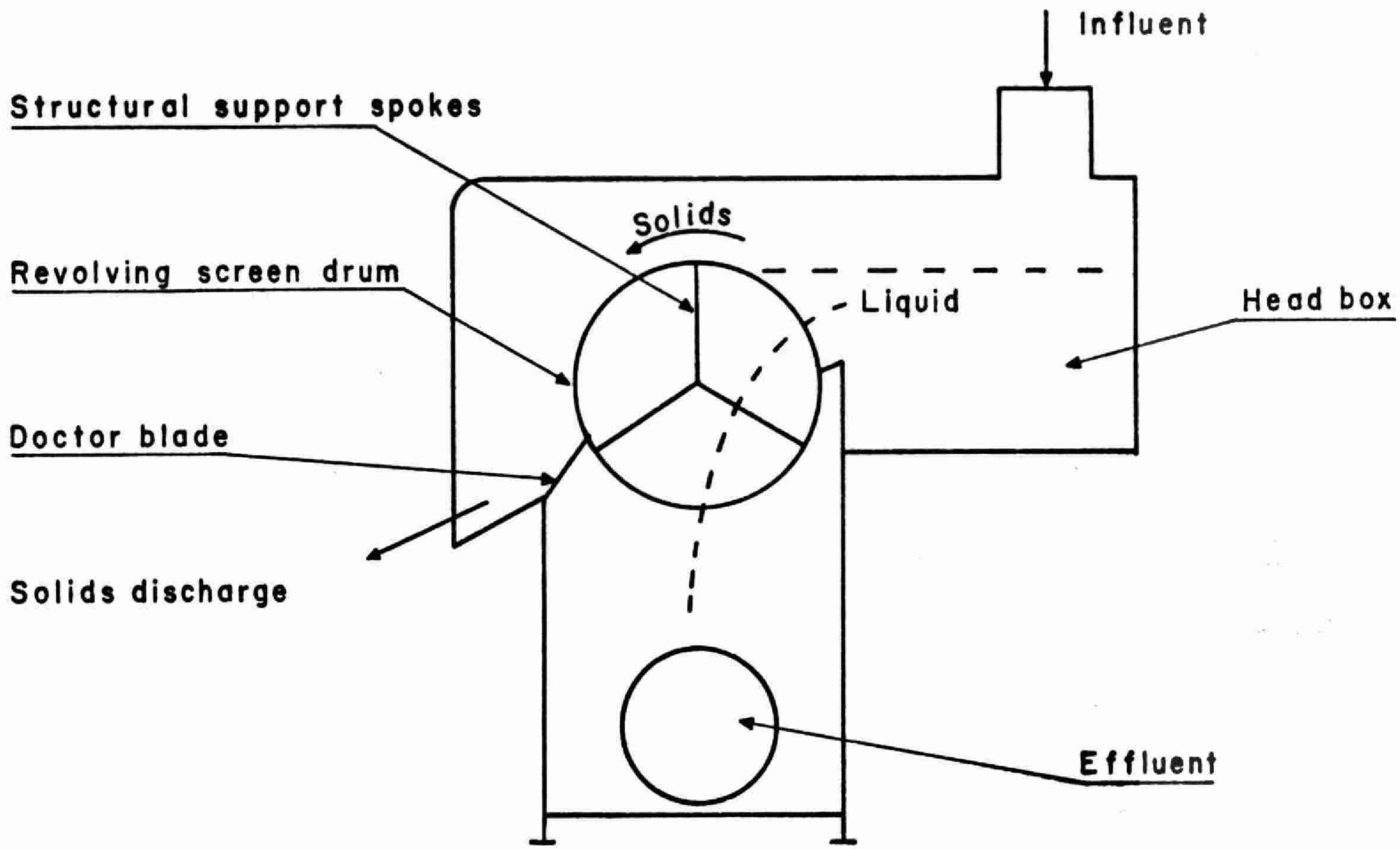


FIGURE: 6 SCHEMATIC OF ROTOSTRAINER.

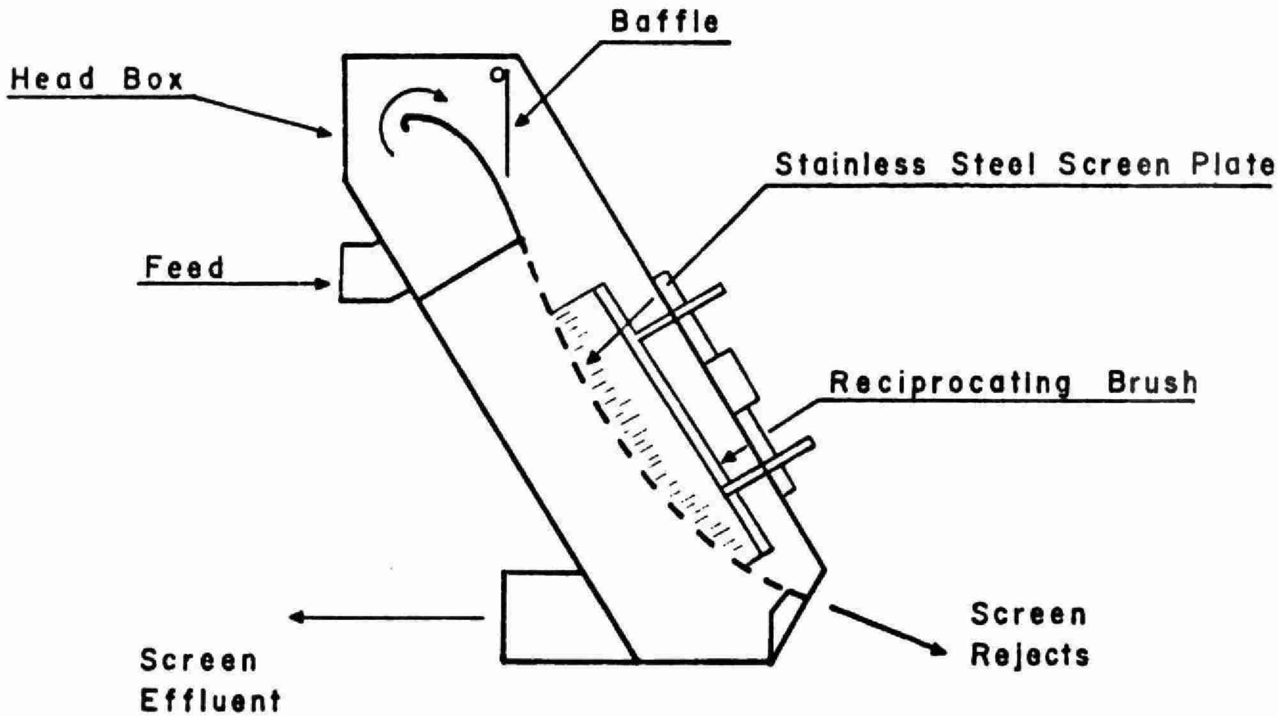


FIGURE 7 SCHEMATIC OF 24" WIDE 45° DSM SCREEN.

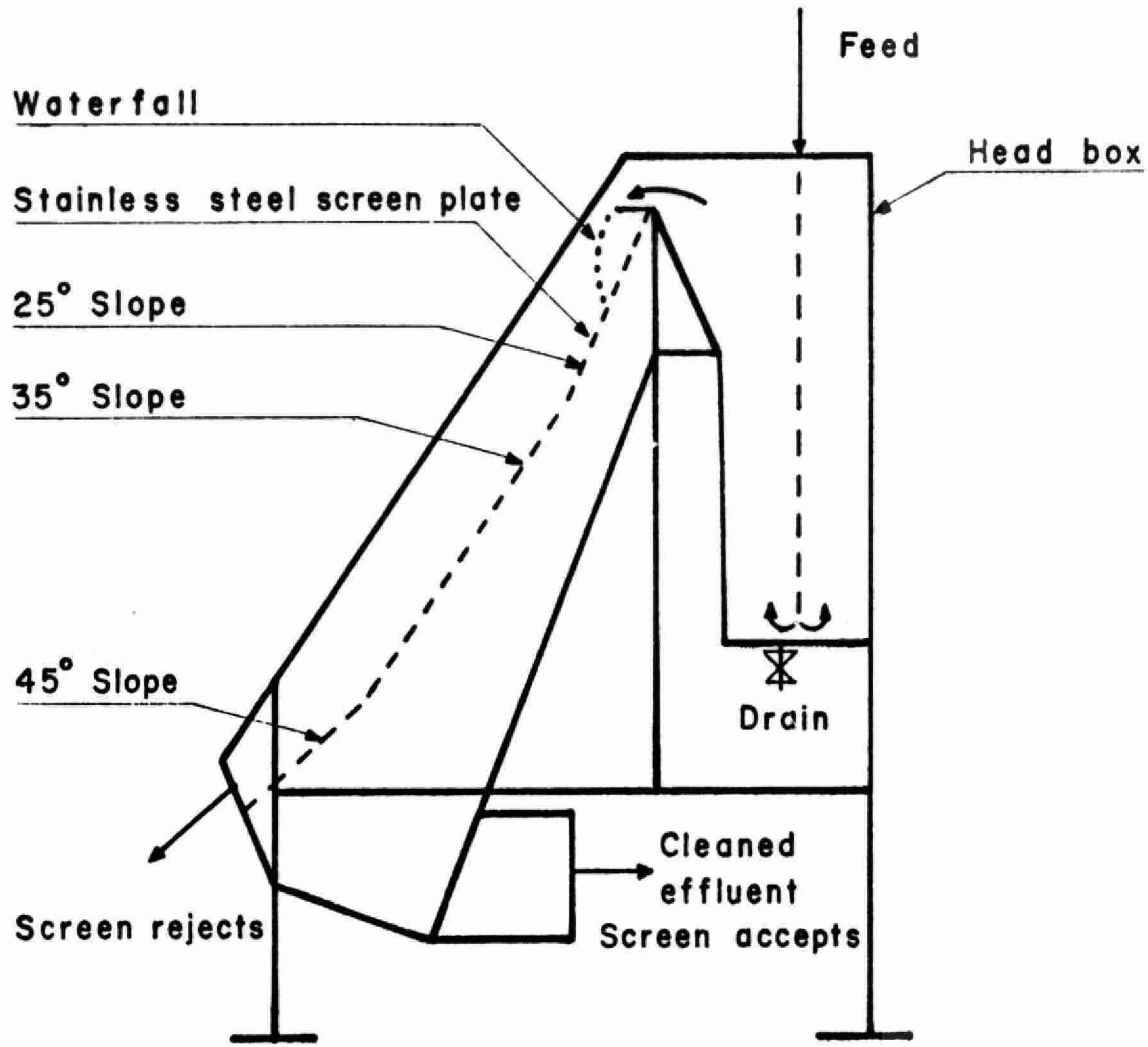


FIGURE: 8 SCHEMATIC OF HYDASIEVE.

showing the basic concept behind each device. Three of the screens produce a clarified effluent and a sludge. The CWC produces a clarified effluent (centrate) and a solids-enriched liquid fraction (concentrate).

The major operating problems associated with the screening devices during the course of the study, the rotary drum screen excepted, was rapid screen blinding due to slugs of industrial oil and grease in the raw sewage. The screen cleaning systems as initially supplied were found to be inadequate to cope with this type of blinding. The CWC, DSM and Hydrasieve all failed to achieve any treatment under some storm conditions because of blinding.

Revamping the backwash system of the CWC and increasing hot water temperature and pressure improved screen operation significantly. Similarly, DSM screen operation was greatly improved upon replacing the backwash sprays with a continuously reciprocating mechanical brush. The brush, however, while effective with a 305 micron screen plate was inadequate for maintaining the next finer screen (150 micron) in a clean condition. The Hydrasieve, needing but lacking any form of screen cleaning equipment, gave unsatisfactory operation at Belleville. The Rotostrainer proved to be self-cleaning during the study. No backwashing of this screen was necessary during normal operation.

Reports from other studies [9] have described damage or blockage to screening equipment from large objects in combined sewage. This was not a major problem at Belleville. However, the influent for the screens was withdrawn downstream of WPCP aerated grit tank.

For the purposes of data analysis, two types of storm conditions were considered, "first flush" and "non-first flush". A storm event was considered to have a first flush when high raw sewage flows due to rainfall were also associated with SS levels of 300 mg/l or higher. Normal dry weather SS levels were in the order of 140 mg/l.

Data gathered under first flush, non-first flush and dry weather were tabulated and analyzed separately. Average combined sewage characteristics with and without first flush conditions at the Belleville WPCP are shown in Table 2. First flush periods typically had a duration of 30 to 120 minutes. The probability of a first flush condition was observed to increase with longer dry weather periods between storms.

TABLE 2. RAW SEWAGE CHARACTERISTICS 1974-75* BELLEVILLE WPCP

		FIRST FLUSH	NO FIRST FLUSH	DRY WEATHER
SUSPENDED SOLIDS	mg/l	522	191	146
VOLATILE SS	mg/l	205	74	77
BOD	mg/l	118	68	94
COD	mg/l	458	204	290
TKN	mg/l	22	19	19.8
TOTAL P	mg/l	5.3	4	4.6
SETTLEABLE SOLIDS	mg/l	6.8	3	5.5

* Arithmetic mean

TABLE 3. HYDRAULIC OPERATING DATA - BELLEVILLE SCREENING STUDY

	FIRST FLUSH	NO FIRST FLUSH	DRY WEATHER
CWC - (105 micron apert.)			
NOMINAL CAPACITY - Imgd	2.0	2.0-3.0	2.0-3.0
LOADING - Ig/m-ft^2*	50	60	60
HYDRAULIC SPLIT - %	70/30	75/25	75/25
CYCLE TIME - min	5	5-10	5-10
HYDRASIEVE - (762 micron apert.)			
NOMINAL CAPACITY - Imgd	0.75	0.75	0.75
LOADING - Ig/m-ft^2	19	19	19
DSM SCREEN - (305 micron apert.)			
NOMINAL CAPACITY - Imgd	0.25	0.25	0.25
LOADING - Ig/m-ft^2	16	16	16
ROTOSTRAINER - (500 micron apert.)			
NOMINAL CAPACITY - Imgd	0.65	-	1.2
LOADING - Ig/m-ft^2	13.5	-	25

* Including allowance for screen cleaning

Typical hydraulic loading and operating data under storm and dry weather conditions are presented in Table 3. The CWC unit is capable of handling a much higher applied loading than the other units but as previously noted, it produces only a solids-rich fraction of the wastewater applied, while the others produce a sludge. During the study, a hydraulic split of 70/30 (ratio of centrate to concentrate) was typically obtained in CWC operation during the first flush of a storm. The sludges produced by the other units ranged from 3% to 8% solids. Solids content varied for each screen depending on the degree of free water draining from the screen and/or free drainage from accumulated sludge on standing. Hydraulic capacities shown for the CWC allow for periods when the unit was shut down for routine backwash. This represents a reduction of about 10% of the nominal capacity of the unit assuming a five-minute screening cycle. All other units were designed to operate continuously during a storm event.

Typical pollutant removals for each type of screen are summarized in Table 4. Pollutant removals, as a percentage, were generally highest under first flush conditions. However, as shown in Table 2, the influent concentrations of the various pollutants were also high under first-flush conditions. As a result, the concentrations of most pollutants in the screened effluents were still high.

While each screen was operated for a different set of storms during the study, the data presented in Table 4 is consistent with the relative pollutant removals observed across each screen. In general, the CWC gave the highest pollutant removals followed in descending order by the DSM screen, Bauer Hydrasieve and Rotostrainer.

Figure 9 summarizes the performance of three of the screens during the first-flush of two storms in which these units were operated in parallel. The relative efficiency of each screen is apparent. The high pollutant concentrations remaining after screening clearly show the limitations of the process under first flush conditions.

Capital and operating costs based on the prevaling conditions of the Belleville study were estimated for three of the screens. Capital cost is shown in Table 5 and operating cost in Table 6. The latter table shows the significantly higher operating costs of the CWC unit and

TABLE 4. POLLUTANT REMOVAL DATA - (PERCENT REDUCTION)
BELLEVILLE SCREENING STUDY

	TSS	VSS	BOD	COD	TKN	P	SETTLEABLE SOLIDS*
CWC (105 MICR.)							
First Flush	31.7	44.6	24.0	23.2	13.2	15.1	79
No First Flush	18.9	28.5	6.4	10.0	3.8	8.0	91
Dry Weather	19.3	25.7	14.7	16.0	9.7	8.7	95
HYDRASIEVE (762 MICR.)							
First Flush	9.4	21.5	5.2	9.6	7.5	6.5	22
No First Flush	8.6	18.5	4.5	1.3	5.5	8.0	5
Dry Weather	7.7	10.0	6.0	-	-	-	12
DSM (306 MICR.)							
First Flush	19.2	34.0	17.8	15.1	9.2	7.6	58
Dry Weather	17.5	17.3	7.3	-	-	-	62
ROTOSTRAINER (500 MICR.)							
First Flush	4.5	11.9	10.1	7.5	2.5	7.2	23
Dry Weather	5.0	5.5	4.5	-	-	-	28

* Based on concentration changes in ml/litre; all others based on changes in mg/litre.

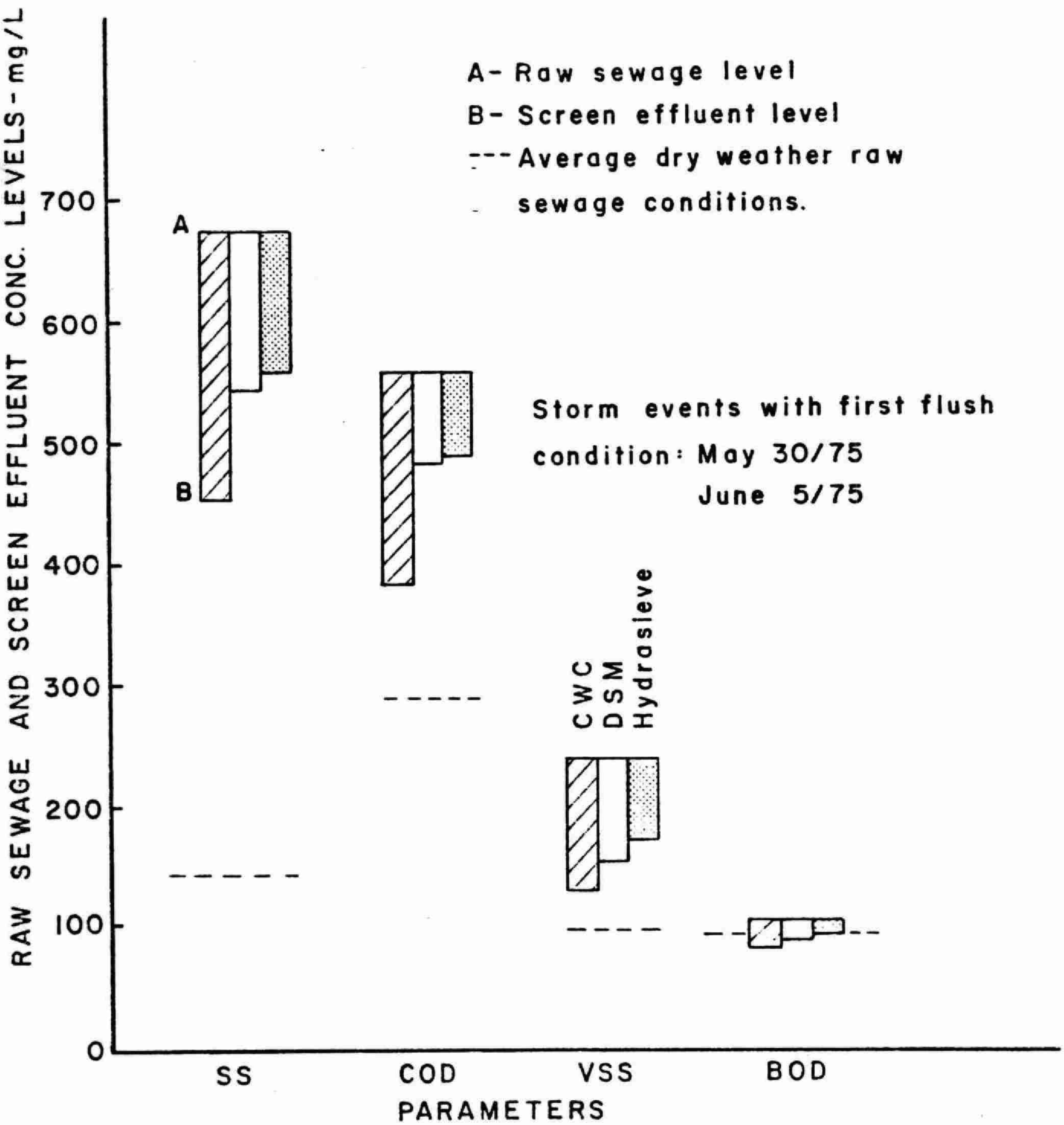


FIGURE: 9 COMPARISON OF SCREEN EFFLUENT CONC. LEVELS CWC vs DSM vs HYDRASIEVE.

the overall sensitivity of operating costs for each unit to the number of operating hours per year.

The results of this study like others [9, 10], confirm the feasibility of high-rate screening of combined sewage. However, the degree of treatment obtained is highly variable depending on the type of screen employed, screen aperture, screen cleaning devices and the ever-changing characteristics of the wastewater.

Of these three screens which operated successfully at Belleville, suitable applications may be found for each in treatment of combined sewage, depending on the end result required. The Rotostrainer seems suitable as a roughing device, the DSM screen as a roughing device which also achieves some pollutant removal and the CWC as a high-rate, high-efficiency unit. The Bauer Hydrasieve operated poorly at Belleville. In studies [9, 11] conducted elsewhere, it has been reported as functioning satisfactorily as a roughing device.

FULL SCALE TREATMENT TECHNOLOGY FOR TREATMENT OF SURFACE RUNOFF

State-of-the-Art

The best developed technology for the treatment of surface runoff is that relating to the design of sedimentation basins "sediment traps" for erosion control in developing areas. Considerable experience has been gained and documented [12] with this type of facility in Maryland, and design methodology is well developed [12, 13].

In the post-construction period, identical or similar ponds have a potential role in controlling the peak rate of surface runoff and acting as pollution control devices to remove BOD_5 or nutrients associated with the suspended solids in surface runoff.

However, there is presently little data available on the effectiveness of ponds for this purpose, nor is there any other well-defined technology which has been demonstrated at large scale for the treatment of surface runoff. It should be mentioned that in Ontario, one recently published site-specific study [14] identified both the phosphorus content and bacterial concentration of surface runoff as having a potentially serious impact on a receiving body and has recognized the desirability of treatment.

TABLE 5. CAPITAL COST OF SCREENING EQUIPMENT

	NOMINAL CAPACITY IMGD	INSTALLED COST** TOTAL COST $	$/IMGD OF CAPACITY
CWC* (1-4 units)	1.8-7.2	40,200-154,000	22,300-21,400
DSM* (1-10 units)	0.75-7.5	17,900-156,800	23,800-20,900
ROTOSTRAINER* (1-3 units)	3.0 - 9.0	52,700-152,200	17,600-16,900

* Based on largest size of screen available.

** Installed cost includes: complete screening equipment with associated screen cleaning equipment, feed pumps, electrical controls, piping and fittings. Buildings, foundations and land costs are excluded.

Hydraulic capacity for costing based on first flush conditions and on gallons applied to each type of screen.

TABLE 6. OPERATING COSTS

DEVICE	OPERATING HOURS/YEAR AT CAPACITY	NOMINAL CAPACITY MGD	COST CENTS/1000 IG
CWC	500	1.8 to 7.2	9.5 to 8.0
	1,000	(1 to 4 Units)	8.3 to 6.6
	6,000		7.2 to 5.6
DSM	500	0.75 to 7.5	3.8 to 3.0
	1,000	(1 to 10 Units)	2.5 to 1.9
	6,000		1.4 to 0.9
ROTOSTRAINER	500	3.0 to 9.0	2.9 to 2.4
	1,000	(1 to 3 Units)	2.1 to 1.6
	6,000		0.8 to 0.7

Cost data based on maximum sized available units.

Operating cost includes: electrical power, propane gas, chemical degreaser, screen replacement, labour cost and maintenance. Amortization is excluded.

Treatment of Surface Runoff in Ontario

Ontario examples of treatment facilities designed for surface runoff are also few in number. Moreover, no permanent facilities are yet operational.

Six projects have been initiated to date, of which four are in the Township of Nepean. These facilities have been installed because the Southeastern Region of the Ministry of the Environment has identified the need for storm water controls to reduce pollution in the runoff from new developments which ultimately drain to the Rideau River.

The two remaining facilities are in the City of Mississauga and are both associated with the construction of artificial lakes fed by the storm water from new development. The primary purpose of these lakes is recreational. They are potential examples of the beneficial use of storm water.

One facility in Nepean Township and one in Mississauga will be described as being representative of two very different sets of design considerations.

Kennedy-Burnett storm water treatment facility

Treatment of storm water was required as a condition of approval for the draft plan of a subdivision for a new urban area drained by the Kennedy-Burnett drain in the Township of Nepean.

Accordingly, the facility described below is being constructed and is expected to be complete by July, 1977 at a cost of $450,000.

The facility consists of a storage reservoir and upstream transport channel (Figure 10) together with necessary drain-down piping and controls, inlet control, structure, bypass channel and an emergency spillway at the basin outlet [15].

Treatment will include coarse screening (trash racks) and settling of suspended matter.

Since the level of fecal coliforms discharged to the Rideau is of major concern at this location, provision has been made in the design for easy addition of post-chlorination facilities and for the dosing of coagulant chemicals to the influent should this prove necessary.

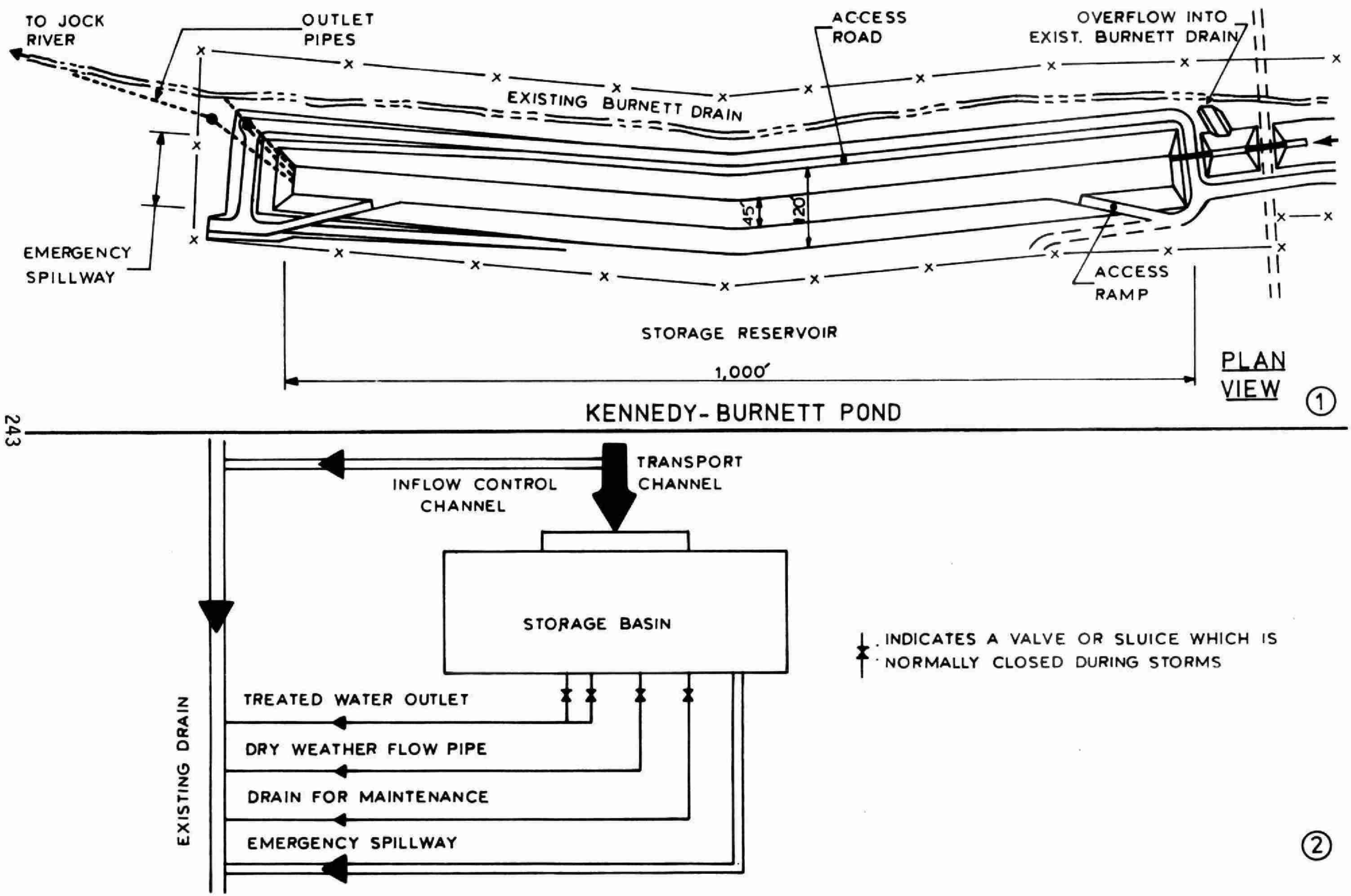


FIGURE: 10 SCHEMATIC OF KENNEDY - BURNETT STORM WATER FACILITY

The design philosophy assumes total containment of a relatively large storm from an initial drainage area of about 300 acres. The design storm is of two hours duration with 0.69 inches/hour of precipitation. The storm is expected to generate a volume of 650,000 ft^3.

Settling time is assumed to be at least 24 hours for the volume contained in the basin followed by a drawdown period of 12 hours. Of the total storage volume required, the transport channel will hold 140,000 ft^3; the basin holds the balance at a depth of 6 ft. The inlet bypass to the basin commences to overflow at this depth. Basin level can continue to rise in extended storms to provide storage of up to 900,000 ft^3, at which point the emergency spillway within the basin will begin to function.

The basin itself will have a plain concrete bottom with paved access ramps to facilitate access for cleaning equipment. The sides of the basin will be protected with rip-rap.

Basin contents will be discharged by sequentially opening two sluice gates at different elevations. An 8" diameter outlet pipe is provided at the "low" (dry weather) water level equipped with an adjustable float control designed to close off the mouth of the pipe on rising water level.

Complete drainage for cleaning can be achieved by means of an 8" pipe below the "low" water level. This pipe has an inlet structure designed to minimize loss of accumulated sludge on drawdown. Sediment storage volume is about 50,000 ft^3 - the necessary frequency of cleaning remains to be determined. The facility will be operated and maintained by the Regional Municipality of Ottawa-Carleton.

<u>Meadowvale West Lake- Mississauga</u>

Construction of this in-line storm water detention lake began in 1976 and is virtually complete.

The 12-acre reservoir and silting basin facilities have been designed to retard storm water runoff from a catchment area of 245 acres, which will be developed in stages, as residential housing.

The surface area of the lake is about 10 acres at normal water level with the silting basin occupying about another 0.8 acres. The

combined area of lake and siltation basin represents about 4 1/2% of the total catchment area. Figure 11 shows the arrangement of the siltation basin and lake.

The lake is located within a park, total area 38.5 acres and its primary purposes are related to its scenic and recreational potential. A variety of nonbody-contact activities such as boating, fishing, etc. are anticipated [16].

An earthen dam has been designed as the detention structure. Normal water depth is approximately 6 ft, which provides permanent storage of 34 million gallons. Maximum design water level during the regional storm is about three feet higher providing live storage of 6.25 million gallons - equivalent to about 1" depth over the catchment area [17]. At this level an emergency spillway will begin to function limiting further rises in level. The outflow control device is a drop-inlet spillway.

The detention facilities provide modest flow attenuation - estimated as reducing peak flows to preurbanized levels or less for storms with return periods of one year or less.

The siltation pond was designed to remove 85% of all particles above 0.07 mm diameter (fine sand) for 96% of all storms [16], and to trap floatables.

A simulation modelling study [17] estimated that the siltation pond would achieve significant capture of pollutants from runoff. For example, in the case of suspended solids, the amount of silt passing forward to the Credit River would be 11 lb/acre/year with the siltation basin, as opposed to 34-171 lb/acre/year without it. The study also predicted that silt buildup would be slow, averaging only 0.05 in/year.

The siltation basin has the potential for becoming anaerobic as pollutants accumulate. The lake may also give rise to algae blooms. Thus, the effectiveness of the lake as a pollution control device remains to be established. Some flow supplementation with city water is anticipated during summer months to prevent too great a variation in lake water level.

Water quality in the lake will be monitored for the first few years of operation to better establish the advantages and disadvantages of this type of flow-through system.

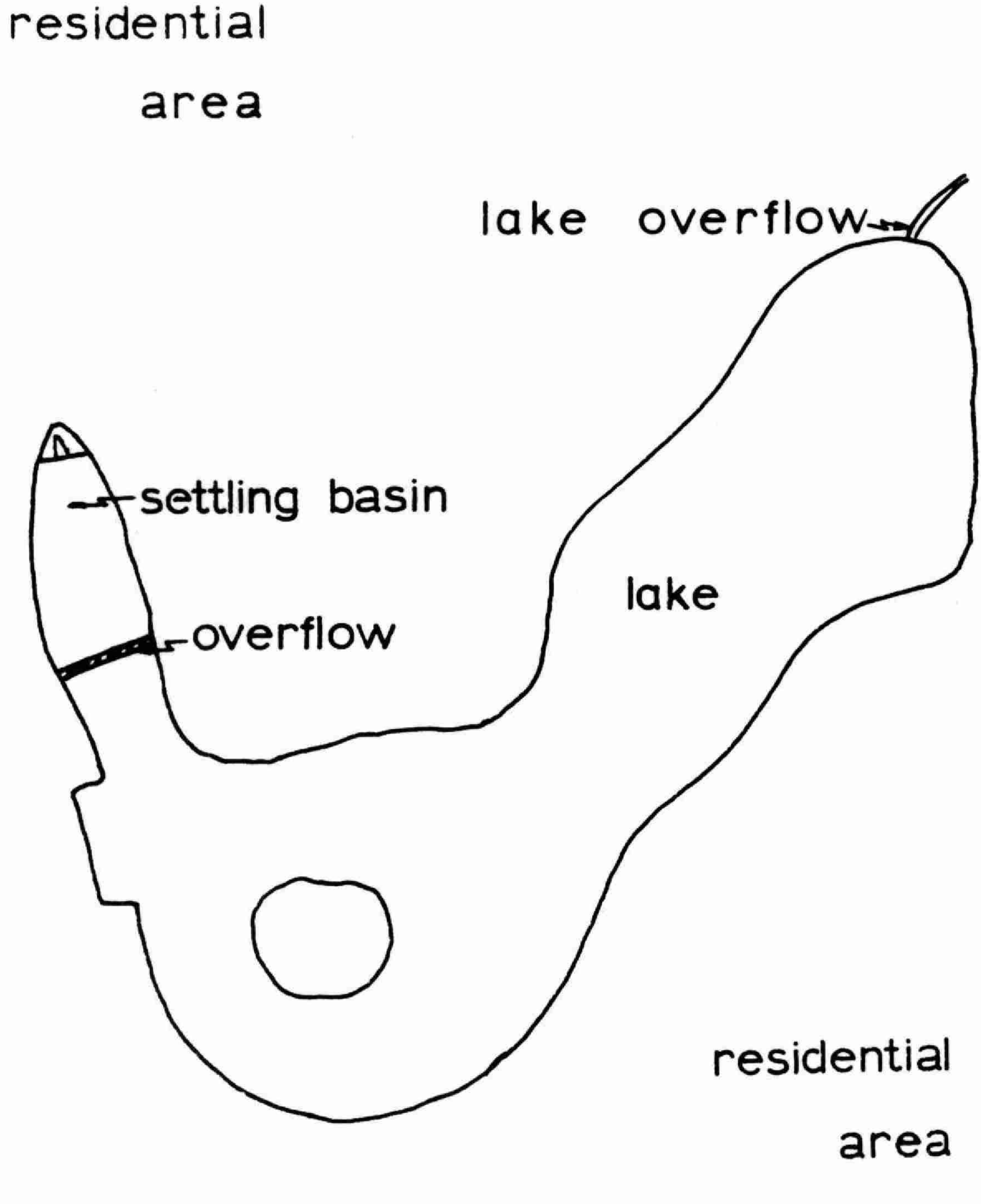


FIGURE 11. SCHEMATIC OF MEADOWVALE WEST LAKE

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A SYSTEMS DEMONSTRATION IN THE CITY OF ST. THOMAS

W.E. Clarke and R.W. Kuzyk
James F. MacLaren Limited

INTRODUCTION

In October 1976 the Central Mortgage and Housing Corporation authorized the commencement of a systems demonstration study of storm water management technology in a municipality with urban drainage problems such as local flooding, combined sewage overflows, and sewage treatment plant bypasses. The study was initiated by the Urban Drainage Subcommittee of the Canada-Ontario Agreement. The site selected for this demonstration study is the City of St. Thomas, which meets all of the criteria with respect to problems and has also committed many of its resources towards the collection of existing data on the existing sewage system, and for the monitoring program which is being carried out for model calibration.

The demonstration study terms of reference require that storm water management models (STORM and SWMM) be used:

a) to assess the magnitude and frequency of pollutant loads to the receiving stream (Kettle Creek);
b) to estimate the relative significance of wet weather and dry weather discharges;
c) to estimate the receiving stream response;
d) to analyse the existing sewage system and sewage system modifications which will provide sewer surcharge control;
e) to test source control, storage and treatment options for storm water management;
f) to test combined options of flood relief and pollution control.

The results are to be conveyed through the determination of cost effective solutions including options which are identified externally to this study.

BACKGROUND

Almost all of the City of St. Thomas lies in Kettle Creek watershed (Figure 1), although a small area at the eastern limits of the City drains naturally to the Catfish Creek. The total area of the City is 4550 acres with approximately 44 percent of this area developed as residential land use; 14 percent as industrial land use; 6.5 percent as commercial land use and the balance, 35.5 percent, comprises open space (Figure 2).

The present population of 27,000 is served by a sewage system that includes combined sewers in most of the older areas, and separate sanitary and storm sewers in all new developments and in some of the older areas of development as a result of a trunk sewer separation program that has been implemented over the past eight years.

However, even though significant strides have been made as a result of the trunk sewer separation work recommended in a 1968 report*, major problems continue to confront the City's administration.

A recent report by the Ontario Ministry of the Environment** which is concerned by the limited assimilative capacity of Kettle Creek, has identified several major options for remedial action for pollution abatement in Kettle Creek. These options are directed towards the combined sewer overflows, sewage treatment plant bypasses and the treated effluent discharges into Kettle Creek and include:

(a) augmentation of flows in Kettle Creek during critical low flow periods (between June and October streamflows fall below 3 cfs 10 percent of the days);
(b) storage of treated effluent to regulate effluent discharge with variations in base flow in Kettle Creek;
(c) increased levels of treatment at the pollution control plant;

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* Report on Storm Relief and Development of Sewerage and Drainage Systems for the City of St. Thomas, James F. MacLaren Limited, December 1968.

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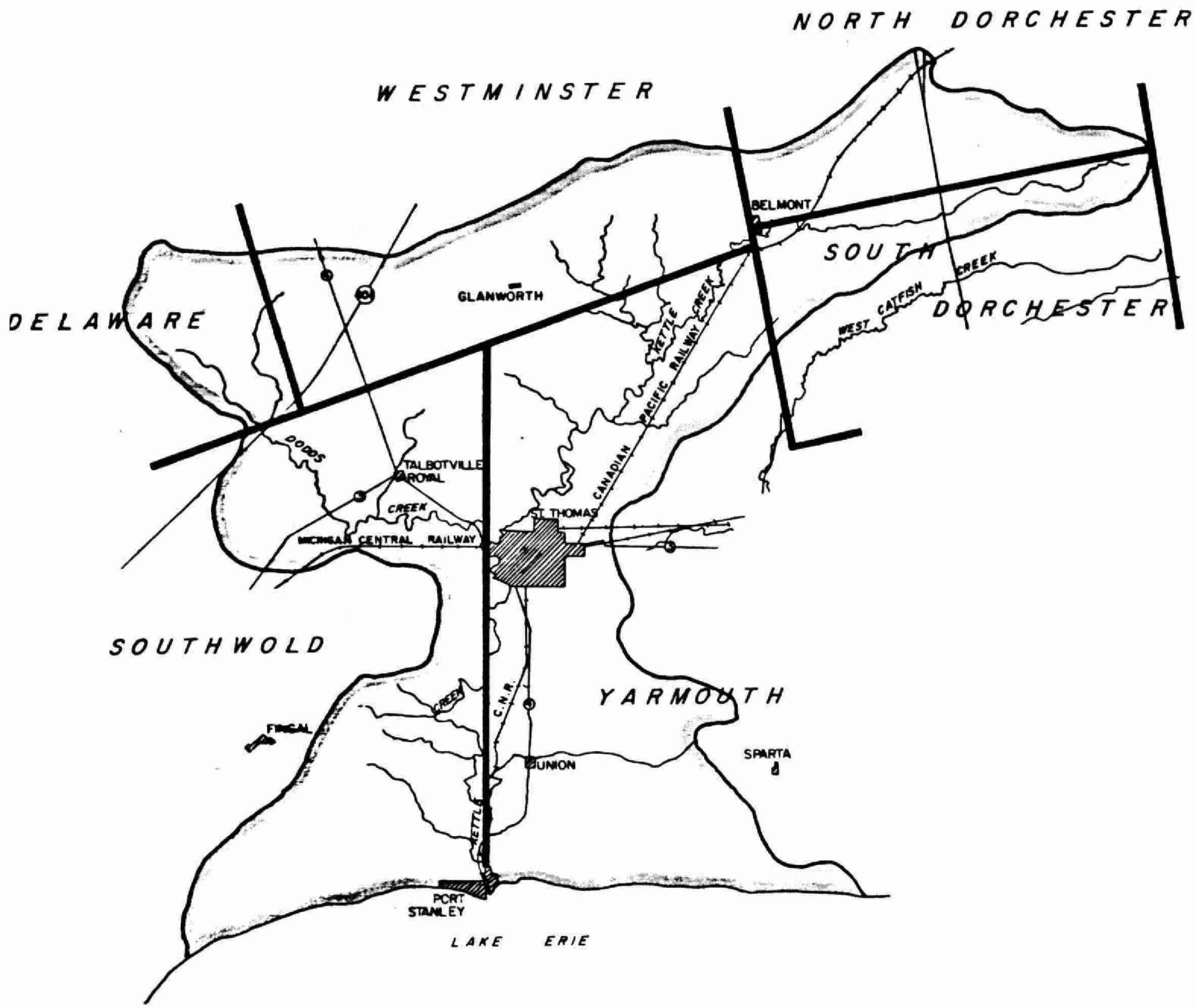
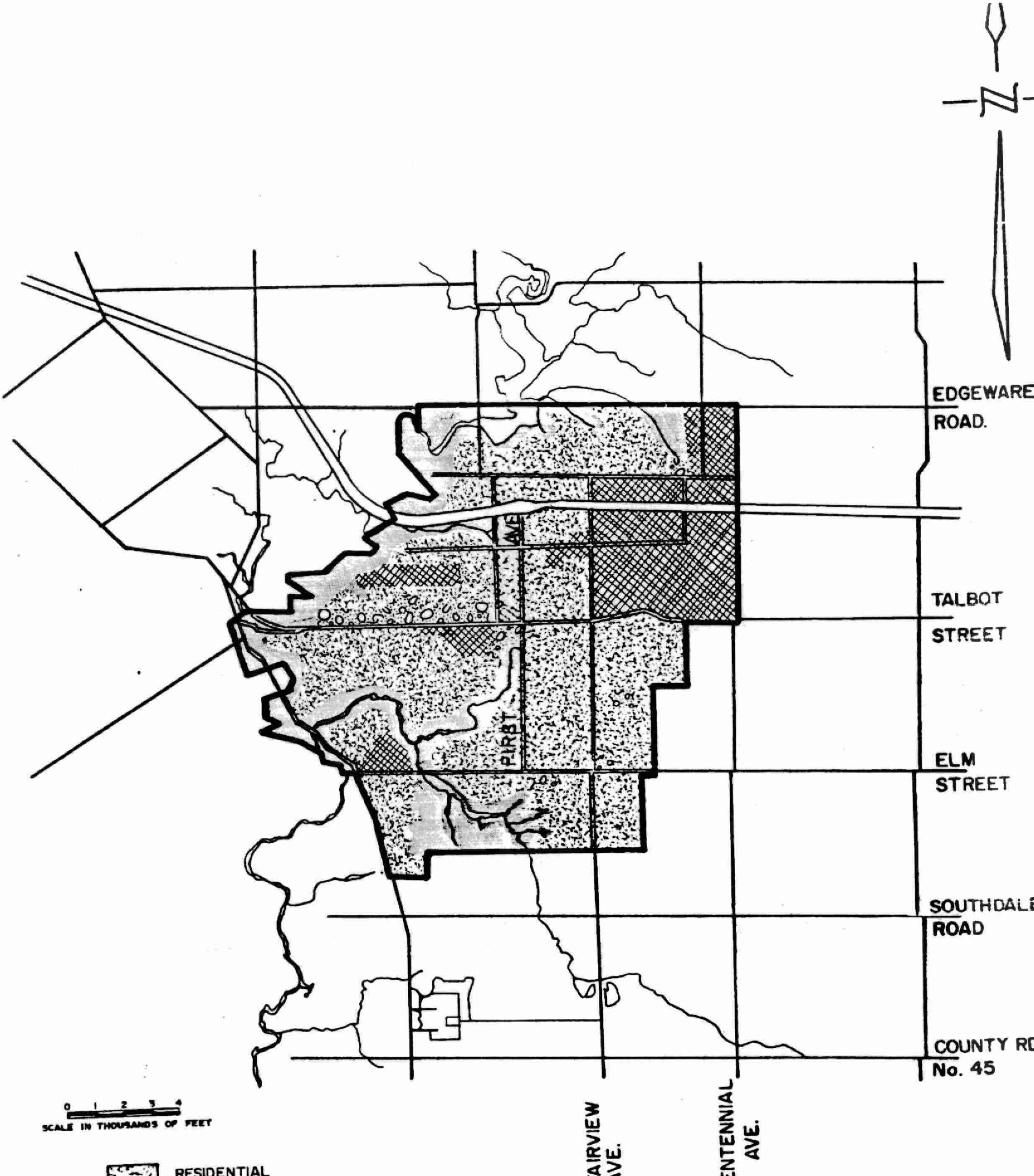


FIGURE 1. CITY OF ST. THOMAS



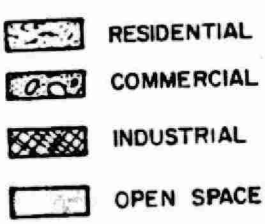


FIGURE 2. ST. THOMAS LAND USE PLAN

(d) diversion of treatment plant effluent out of the Kettle Creek with discharge directly into Lake Erie.

This study by the Ministry of the Environment did not include the related problems of urban drainage discharges to Kettle Creek within its terms of reference nor were the problems experienced with local street or basement flooding included.

The current study is concerned with all of these problems and is endeavouring to identify the most cost-effective solutions.

METHODOLOGY

In the general framework of the study, the investigation of water quality problems and the assessment of relief measures for basement flooding, form two relatively independent activities. However, the possibility that certain combinations of alternative solutions to these problems may be interrelated will also be considered.

The flood relief analysis is being carried out using the SWM model with the WRE transport routine for hydraulic routing. The SWMM Runoff routine permits the analysis of management techniques such as on-site detention of runoff while the WRE transport routine will be used to accurately analyse the existing and proposed systems under surcharged conditions and to evaluate in-system storage as a relief alternative. A detailed analysis will be done on all existing pipes to determine the extent of lateral sewer and trunk sewer relief required. A comprehensive review is also being conducted of all possible flooding relief measures such as source controls, in-system storage, separation (partial and complete), roof disconnection and the management of new land development.

The model simulation of local basement flooding will be calibrated using measurements on a 13-acre catchment within the study area, during this spring and summer.

The problems of storm water quality are less well defined than those of runoff quantity. This is particularly true where the receiving water response must also be evaluated in addition to estimating pollutant loadings from runoff. In the St. Thomas study, a two stage, two level approach is being pursued. During the first stage a simplified methodology is being applied to determine the order of magnitude of the water quality

problem and to pre-screen potential abatement measures. The STORM model has been used to predict the quality of runoff from all events over a nine year historical period corresponding to the available streamflow record. The entire city was divided into one separated and one combined sewer district for this analysis, and the pollutant loading rates in the model were adjusted to compare with recorded values from other Canadian cities.

The receiving water dissolved oxygen (DO) response to TOD (total oxygen demand) from storm runoff and combined sewer overflows was estimated for each event using the 'Streeter-Phelps' equation to compute DO deficits. A similar analysis was done for the impact of the treatment plant effluent during dry weather flow conditions. In both cases measured streamflows and stream quality conditions derived from previous studies were used.

To assist in the pre-screening of abatement alternatives a scoring matrix was developed similar to that developed for the relief alternatives. At this stage in the study, engineering judgement and the results of the pre-screening matrix are being used to select those alternatives to be investigated in more detail.

In the second stage, the STORM model will be calibrated using the results of the spring and summer monitoring program in several catchments with varying land use. The runoff pollutant loadings will then be recomputed with STORM using a more detailed schematization of the city. For selected critical events the proposed abatement alternatives will then be evaluated according to their effectiveness in reducing pollutant discharges, the potential improvement in dissolved oxygen levels in the creek and their cost. The analysis of the receiving water response to these loadings will also be demonstrated using the SWMM Receive routine to model the creek for selected events. However, calibration of the SWMM Receive routine is not included within the terms of reference of the study.

RESULTS

At this time, this demonstration project is at its half way point. Several different stages of the work have been completed but a good deal of the work remains to be done.

Both STORM and SWMM have been set up for use. However, to this time all pollution abatement simulation has been carried out with the

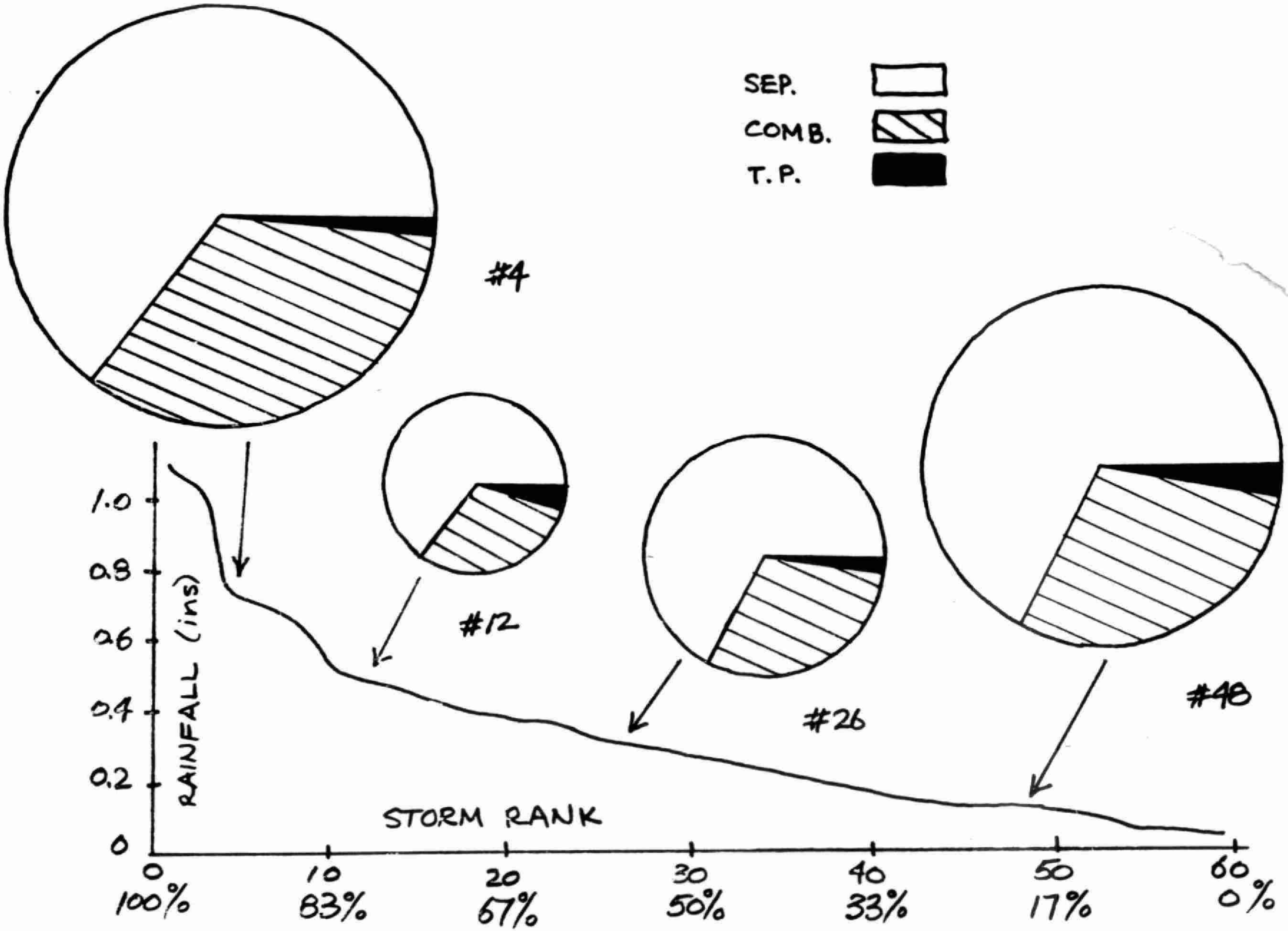
STORM model considering the entire city as two drainage areas. This preliminary, coarse analysis has helped to identify the critical events and further has permitted an approximate quantitative comparison of wet weather loadings with the amount of BOD discharged in the treatment plant effluent. It was found using STORM results that during most storm events, the BOD entering Kettle Creek from storm runoff and combined sewer overflows greatly exceeds the BOD discharged from the treatment plant (Figure 3). On an annual basis for an "average" year even though the volume of discharge from the treatment plant exceeds the volume of wet weather discharges, the loading of BOD and suspended solids is greatest from storm outlets (Figure 4).

The Streeter-Phelps analysis has quantitatively approximated the impact of wet and dry weather loadings on Kettle Creek. From this analysis it is concluded that dry weather and wet weather problems are equally significant, both resulting in a large number of violations in terms of maintaining a desirable concentration of dissolved oxygen in Kettle Creek.

Figure 5, showing the average monthly streamflow and the variation in BOD for an average rainfall season (April to October), illustrates graphically the problem of assimilative capacity in Kettle Creek.

This work is continuing and will identify those critical events which will be simulated on the SWMM Runoff and Receive Blocks. Monitoring of rainfall events has been planned and will take place within the next few months. With calibration of the model, simulation of various control alternatives will be carried out.

Nonquantitative evaluation of these various alternatives is being carried out using a scoring matrix. Preliminary screening is considering many varied objectives and their characteristics including practicability, reliability, public health and safety, aesthetics, public acceptance, odour and noise creation potential, impacts on land, etc. These evaluations, together with the quantitative evaluations of the various alternatives for potential pollution abatement and cost, will comprise the input to a final decision matrix which will consider the selected alternatives and various combinations of alternatives.



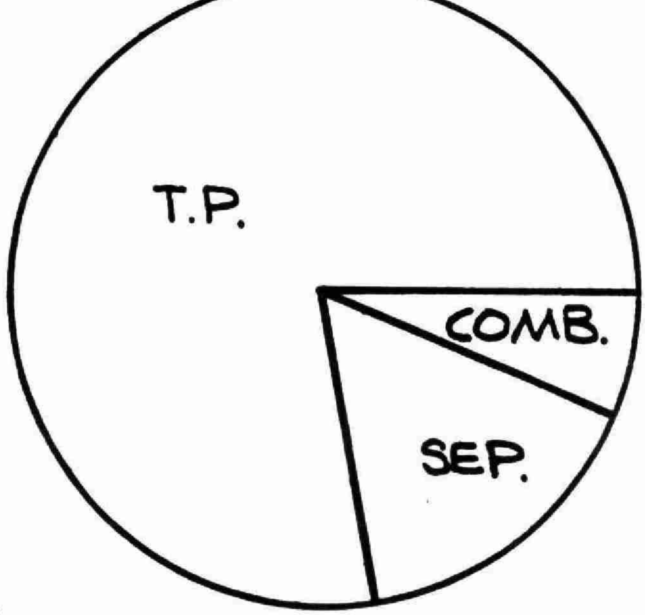
FIUGRE 3. BOD LOADING FOR SELECTED EVENTS (1974)

VOLUME

T.P. 300 $ft.^3 \times 10^6$
COMB. 25 "
SEP. 63 "

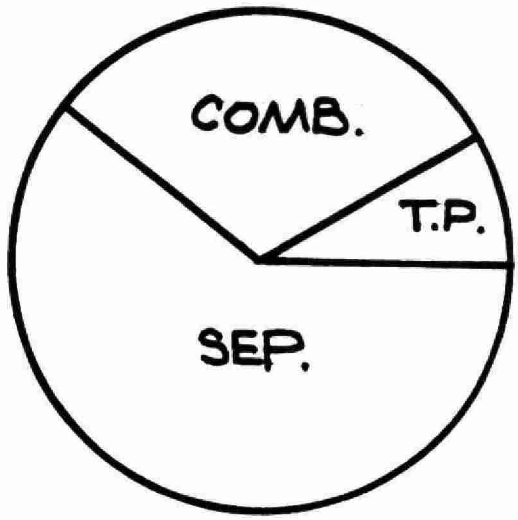
~ 6" RUNOFF

NOTE: 1. T.P. CONSIDERED FOR 365 DAYS.
2. RUNOFF DOES NOT INCLUDE SNOWMELT.



SUSP. SOLIDS

T.P. 220 $lbs. \times 10^3$
COMB. 800 "
SEP. 1500 "



B.O.D.

T.P. 220 $lbs. \times 10^3$
COMB. 130 "
SEP. 160 "

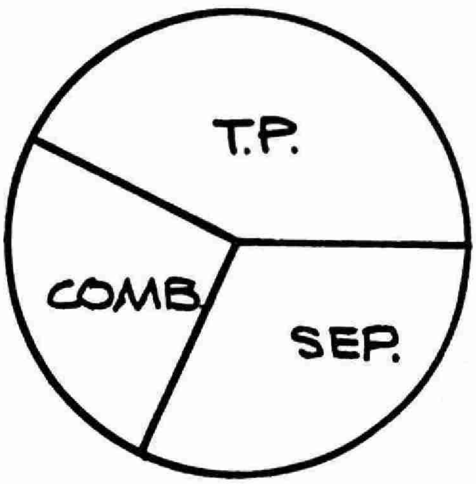


FIGURE 4. ANNUAL LOADINGS

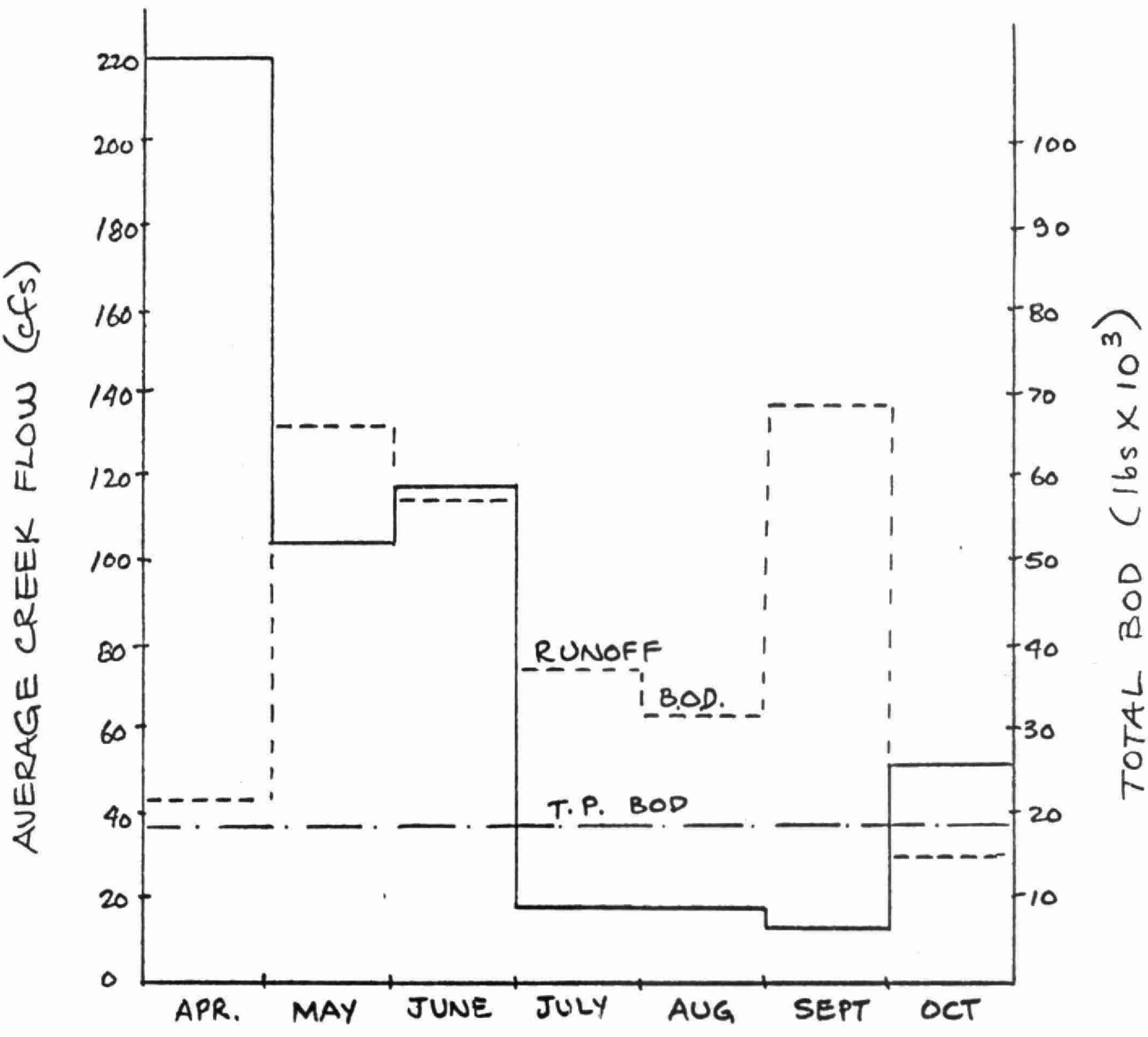


FIGURE 5. BOD LOADINGS VS. STREAMFLOW

The alternatives identified for pollution abatement include:

source controls	- street sweeping practices
	- de-icing salts and chemicals
	- fertilizer, pesticide and herbicides
	- roof and parking lot storage
	- depression storage
	- rainfall leader connections
	- erosion control
collection system controls	- catch basin cleaning
	- line flushing
	- sewer separation
	- infiltration/inflow
	- regulators for interceptors
	- real time control
storage/treatment	- inline storage
	- offline storage
treatment	- increase in plant capacity
	- alternatives for storm water
flow augmentation for Kettle Creek	- wells, diversion, dams
dry weather flow	- treatment level
	- effluent storage
	- pipeline to Lake Erie

In the separate analysis of the flood relief problems a carefully selected portion of the city has been selected for detailed analysis with SWMM, and the area has been discretized. However, no results have been produced prior to preparation of this paper. A similar type of screening matrix will be utilized to evaluate the flood relief alternatives which include many of the source runoff controls and collection system controls identified for the pollution abatement alternatives. Additional alternatives for flood relief include:

(a) offline storage with controlled discharge

(b) reduction in rate of flow by design of conduits

(c) replacing undersized sewers

(d) diversion of flows.

In summary, although urban drainage comprises a major portion of the St. Thomas Study, it is so interrelated with other aspects of pollution abatement for Kettle Creek that only through modelling can an appreciation of all the facets of the problem be realized and real, comprehensive, effective solutions identified.

URBAN DRAINAGE DESIGN FOR NEW DEVELOPMENT

Paul E. Theil,
Paul Theil Associates Limited

INTRODUCTION

Most of our engineering standards have been established for many years and have become old tradition. Some will be found as valid to-day as when they were established, but it should be of no surprise to anyone that many have become obsolete.

Nowhere is this more true than in the field of urban drainage. The prevalent philosophy in most Ontario municipalities stresses the importance of collecting as much of the storm water as fast as possible for discharge through our sewer system to our streams and lakes. This has resulted in:

a) high peak flows in storm sewers and streams which require larger facilities at higher cost;
b) lowering of water tables, with a detrimental effect on existing vegetation;
c) reduction in base flows in receiving streams, affecting aquatic life;
d) higher discharge velocities, resulting in excessive erosion of streams and sedimentation in lakes;
e) increased pollution of receiving streams and lakes due to industrial fallout on roofs, fertilizers from lawns, and debris from streets and paved areas;
f) increased danger of damage due to flooding. Runoff quantities which had been experienced rarely, now begin to occur much more frequently. The annual damage from flooding is increasing at an alarming rate.

Nature meant most of this water to soak back into the earth; present practices prevent it.

In spite of the present high cost, damage from flooding - even in new urban areas - continues to occur, but this we conveniently classify as an "Act of God", although in many cases such could have been prevented if a more logical approach had been taken.

It took years to notice that a new set of problems has been created. Indeed, all that has been done in the past has been to move the problem from one location to another, and we have ended up with more serious problems than we started with.

The obvious approach is to design the storm drainage system to correspond as closely as possible to nature's demand; that is, direct the storm water into the soil, preferably to the same extent as nature now does prior to development, and maybe to an even greater extent. Whatever amount cannot be so accommodated at the point of rainfall should be detained in nearby locations for a controlled outlet to the receiving streams, with peak flows preferably set to the pre-development conditions. This condition has been termed "zero increases in storm water runoff".

New concepts of storm water drainage have been developed in recent years, but very few have been adopted in Ontario as yet. After an extensive study of these concepts, and evaluating the results from actual installations, our firm is using a new design approach which is explained in its basic form in the following design example. Due to the time limits imposed for this presentation, the technical details are not as extensive as I would have liked to present, but are stated in their basic form only. For the same reason, the example does not cover the design techniques for other important new concepts such as:

- surface infiltration basins;
- detention basins;
- "blue-green" storage; and
- hydro-brake regulators.

DESIGN EXAMPLE

Objective

To provide a design example of a new residential subdivision with special emphasis on demonstrating the role of the major (surface) and minor (storm sewer) drainage systems, the use of the Foundation Drain Collector (F.D.C.) system and an example of reduction in the rate of storm runoff.

criteria from a two-year to five or even ten-year rainfall frequency. This conflicts with the present emphasis on reducing runoff, but even if it did not, many indeterminable factors not yet recognized in storm drainage design will make it impossible for the designer to predict with any degree of accuracy what storm frequency the system will actually be able to handle before hydrostatic pressure will occur on basements. Due to the variations in storm patterns and runoff conditions, a system designed for a ten-year frequency may, in some areas, be able to accommodate a storm of much higher intensity, and in other locations considerably less. With a different storm pattern the condition could be reversed.

If foundation drains are connected by gravity to storm sewers of less capacity, protection against flooding of basements cannot be obtained. Gravity connections to the storm sewers are, therefore, not a practical solution.

Other possibilities could be sump pump installations which can discharge to the ground or to a storm sewer; either method is technically sound although more costly than connecting to a sanitary sewer. This would transfer the problem to the individual homeowner, who may not be too pleased with a device which, as a result of mechanical or power failure, may cause flooding to his basement. The resulting damage, however, would not cause structural failure to the basement, as pressure equalizes inside and outside. Even though the inflowing water would be relatively clean storm water rather than sewage, this solution does not seem very desirable when projected for areas expecting a large urban growth.

An alternative solution is a separate foundation drain collector, being a third pipe installed in the same trench as the sanitary sewer but with connection to foundation drains only [2]. The method has several advantages and, particularly for new areas to be developed, it may be the best solution. A foundation drain collector will:

(a) eliminate probability of hydrostatic pressure on basements due to surcharged sewers;
(b) eliminate infiltration into sanitary sewers from foundation drains;

(c) permit shallow storm sewers, design for lower rainfall intensity, and reduce length of storm sewers, resulting in cost savings for the storm sewer system;

(d) permit positive design of both the minor and major storm drainage systems.

Since it does require an outlet with free discharge even during severe storm conditions, it may not be practicable in all areas, particularly within built-up areas where storm sewer outlets have already been provided. This method should be considered as an alternative solution in areas where infiltration can be expected to be too high for connection to the sanitary sewer.

Methods to reduce storm water runoff

In the interest of minimizing the adverse effects of increased storm water runoff due to urbanization, various methods to reduce storm water runoff have proven very effective. In this example the following techniques have been included:

(a) Roof drains discharged to lawns [1, 3].

(b) Rooftop storage [3].

(c) Subsurface disposal [4].

Whereas the advantages of the first two methods are well known, at present only limited Canadian experience is available in the subsurface disposal method.

Recharging storm water back into the ground close to the point of rainfall is one of the more beneficial ways to treat storm water runoff. This is particularly adaptable to pervious soils, where in some instances the total runoff can be discharged without the need for extensive storm sewers or drainage channels. A percolation trench usually will consist of a perforated storm sewer surrounded by a filter material consisting of clear cut stone with a high void ratio. In order to prevent these voids being filled by fines from the surrounding soil, an interface material, such as nonwoven drainage filter cloth, may be required. Where the pervious material is at a substantially lower level, vertical shafts can be installed. To reduce the possibility of clogging the filter with

solids carried by the runoff, which occurs primarily during the "first flush", filter bags made of filter cloth can be effective if placed in catch basins.

The concepts used for detention and reduction of storm water runoff not only regulate the amounts and rate of runoff of storm water, but also are an important factor in reducing pollution. Sedimentation basins, underground recharge systems and detention facilities all have treatment capabilities. Runoff from roofs, directed over grassed surfaces rather than being piped directly to a storm sewer, will receive a substantial reduction in pollution through its travel overland or through percolation into the soil. Perforated storm sewers with a properly designed filter material will permit initial runoff (the "first flush") which contains most of the pollutants, to be temporarily stored in the underground system for gradual percolation into the soil. The voids in the stone filter material will permit treatment of pollutants somewhat similar to the action of a septic tile bed. To prevent possible pollution of groundwater serving domestic wells, the subsurface disposal system should not be placed where such possibility exists but should be located in accordance with the requirements for septic tile beds.

A design manual is presently being prepared in the United States outlining methods of design to suit various conditions. The design example illustrates a very simple method now being used in some locations.

DESCRIPTION OF SITE

The site as shown on Figure 1 and used for this design example is typical for a residential development in southern Ontario. Although the site represents an actual development, the design contained herein has been modified somewhat in order to illustrate the design techniques more clearly.

The site is about 100 acres in size and contains lots for single family and semi-detached housing as well as a site for a public school. The site slopes generally from west to east, where it is bounded by a major open watercourse. To accommodate the principles of the "minor-major" storm drainage systems, the streets have been planned to conform

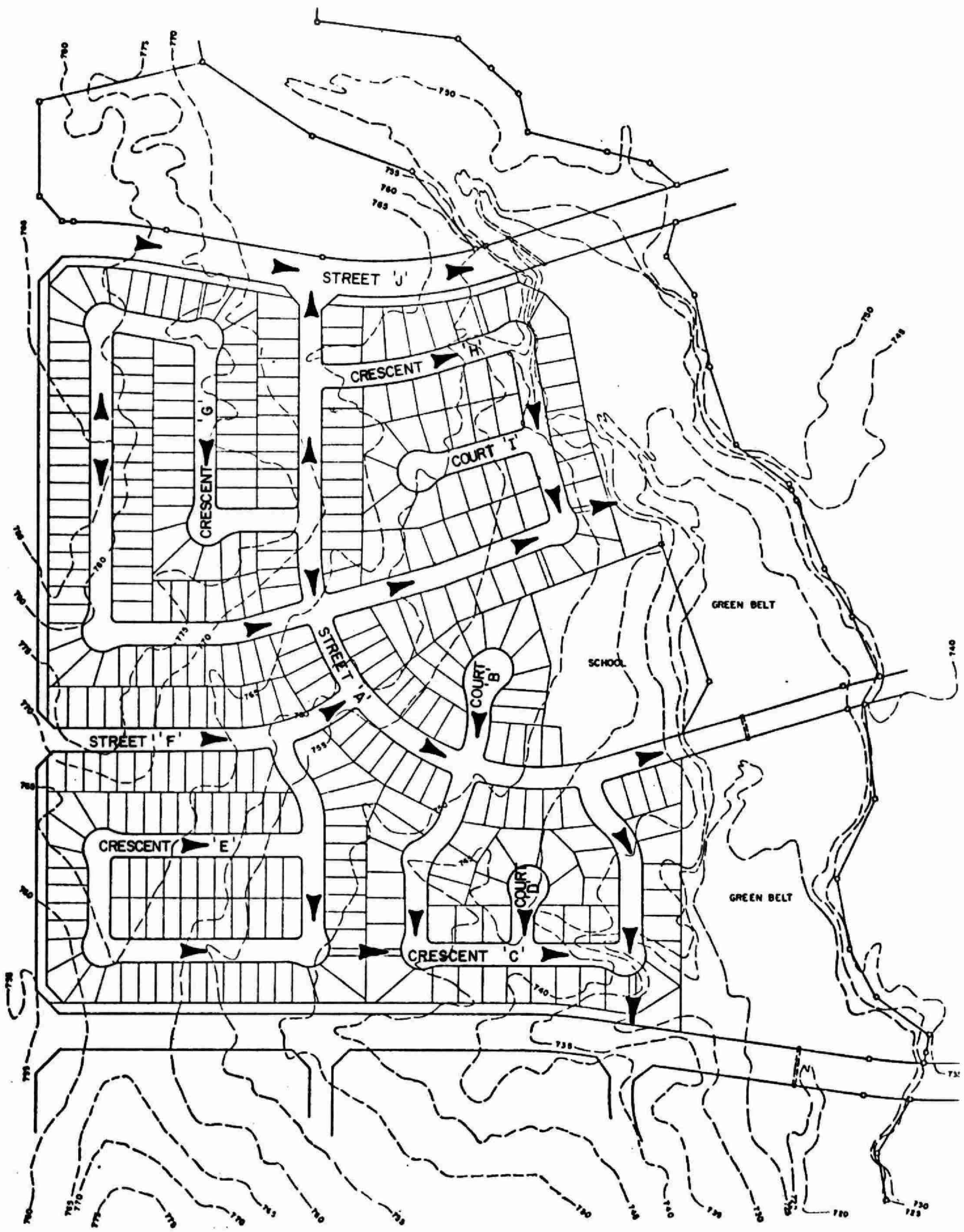


FIGURE 1. SITE PLAN WITH ROUTE OF SURFACE RUNOFF

as much as possible to the natural contours of the land. Where sags in roadways between intersections could not be avoided, overflow easements or walkways have been provided to permit unobstructed surface runoff during major storms, as shown on Figure 1.

SELECTED DESIGN CRITERIA

Minor System

Based on a reasonable level of convenience to the public, a two-year design curve is considered adequate as a design basis for the minor system within this development.

Major System

The major (or overflow) system will first be checked against a 100-year storm intensity. Since the site abuts a major open watercourse no difficulties are expected in achieving this criterion. However, should this not be practical, calculations will be made for a lesser storm intensity, with 25-year intensity being the absolute minimum. The maximum depth of overland flow for this development has been arbitrarily selected as 8 inches above centre line road for local streets, and 6 inches on collector streets [5]. To prevent flooding of basement garages, driveways will have to meet or exceed the corresponding elevations at the sidewalk or street line. Since the runoff coefficient in the Rational formula does not account for many hydrological factors such as antecedent moisture conditions, the U.S. Soil Conservation Services (SCS) method will be used for estimating the runoff for the major storm.

Foundation Drains

The design example is assumed to be located in a municipality which, as a policy, will not permit foundation drains to be connected to the sanitary sewer. This leaves only the possibilities of sump pumps or a separate foundation drain collector (F.D.C.) system open. Since the total end costs for these two methods are expected to be about the same, the latter method is chosen as being preferable. The design criteria for an F.D.C. must be based on many factors such as soil conditions, water table fluctuation, lot grading control and the method used for discharging roof water.

Since test measurements were not previously taken in this area, an assumed peak flow of 0.0027 cfs per unit was selected, based on criteria established by the City of Mississauga [6]. This amount includes infiltration to the collection system. For areas over 100 acres, the flows can be considered to decrease to 0.001 cfs per unit for 10,000 acres and larger. (Ongoing monitoring of flows from F.D.C. systems indicates flow very much below the above amount, but until extensive data is available, the designer should use a very safe design flow).

Rooftop Storage

The design criteria for roof top storage has been set to permit maximum storage on flat roofs to be within the snow load requirements, which for Toronto is 40 lb per sq. ft. equivalent to 7.7. inches of water. With this maximum allowance, no additional costs will be incurred for roof construction. The controlled flow roof drains will permit continuous flow at reduced rate, with overflow provisions for depths exceeding the stated maximum.

Subsurface Disposal

The criteria to be used for design of the subsurface disposal system is based on the percolation rate of the soil, which has been assumed to have been tested and found to be two inches per ten minutes.

DESIGN CALCULATIONS

Minor System

The limited extent of the area involved and designing on the principles of the minor-major drainage concept permits considerable tolerance in the degree of accuracy of runoff calculations such that the rational formula $Q = A \times i \times R$ is considered adequate for the minor system [7]. The values for the two-year rainfall intensity curve are shown on Table 1. Storm drainage areas are shown on Figure 2.

The entry time has been selected as ten minutes. (Roof water not connected directly to storm sewer.) The runoff coefficient has been determined based on 0.20 for grassed areas (and areas discharging to grass such as roofs, patios and sidewalks) and 0.95 for impervious surfaces (streets and driveways), which for this site results in an average runoff coefficient of 0.35.

TABLE 1. RAINFALL INTENSITY DURATION FREQUENCY

TIME (MIN)	2-YEAR RETURN (in/hr)	10-YEAR RETURN (in/hr)	100-YEAR RETURN (in/hr)
5	4.15	7.50	10.33
10	2.85	5.00	7.04
15	2.25	4.00	5.74
20	1.88	3.45	4.80
25	1.65	3.00	4.30
30	1.47	2.70	3.81
35	1.32	2.45	3.50
40	1.20	2.25	3.20
45	1.10	2.05	2.90
50	1.04	1.90	2.70
55	0.96	1.75	2.50
60	0.88	1.60	2.31
65	0.81	1.50	2.15
70	0.75	1.45	2.00
75	0.69	1.35	1.85
80	0.63	1.30	1.75
85	0.58	1.20	1.63
90	0.53	1.15	1.55
95	0.49	1.10	1.50
100	0.45	1.08	1.30
125	0.40	0.90	1.27
150	0.35	0.80	1.00
175	0.31	0.70	0.90
200	0.27	0.65	0.86

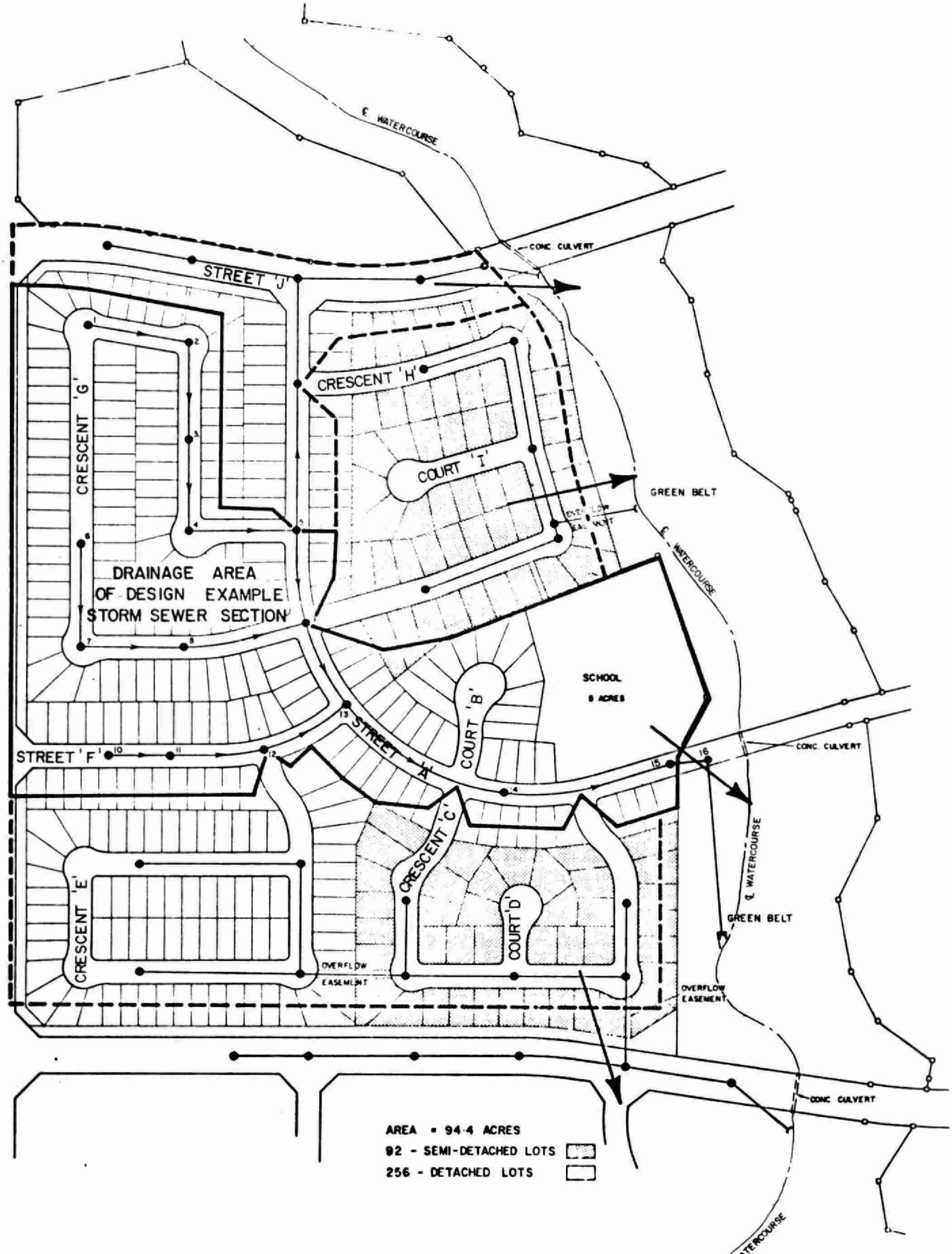


FIGURE 2. STORM DRAINAGE AREAS

The actual design calculation is shown on the storm sewer design sheet Table 2.

Major System

The calculations for the major storm will be based on the U.S. Soil Conservation Services (SCS) method, as described in SCS Technical Release No. 55, chapter 5. It is a graphical approach for estimating peak flows from storms of 24-hour duration, in areas up to 20 square miles, based on the time of concentration, and the cumulative runoff over the 24-hour duration. It should be realized that this method provides approximations of the peak flows as do most of the manual methods employed today, and cannot take the place of the more sophisticated computer programs useful in complex drainage areas. The SCS method was preferred over other conventional methods because it takes into account most of the hydrological factors such as antecedent moisture conditions, infiltration, soil type and storm distribution. These factors are based on empirical relationships which have been determined from rainfall and runoff readings over a large number of drainage areas.

The application of the SCS graphical method follows below:

Given: Drainage area: 38.01 Ac = .06 M_1^2
Hydrological soil group: B (Table 3)
Runoff curve number: CN = 74 AMCII (Table 4)

The major system will be designed to provide protection against a 100-year storm, based on data from the Atmospheric Environment Service, Fisheries and Environment Canada.

Storm frequency = 100-Year
24-hour cumulative rainfall = 5.39 inches

Three levels of Antecedent Moisture Conditions (AMC) are considered in the SCS method. It is defined as the amount of rainfall in a period of 5 to 30 days preceding the design storm. In general, the heavier the antecedent rainfall, the greater the runoff potential.

AMC I - Soils are dry but not to the wetting point. This is the lowest runoff potential.

TABLE 2. STORM SEWER DESIGN SHEET

Q= AIR
A= AREA IN ACRES
R= COEFFICIENT OF RUNOFF
I= INTENSITY OF RAINFALL FOR PERIOD IN INS/HR.

STORM SEWER DESIGN

MUNICIPALITY:

DISTRICT OR SUBDIVISION NAME:

DESIGN SHEET 1 OF 1
DESIGNER P.T.A.L. DATE Feb./77

LOCATION			RUNOFF			TOTAL SECTION AR	TOTAL TRUNK A.R.	INTENSITY I INS/HR	Q C.F.S.	LENGTH OF PIPE	SIZE PIPE IN.	SLOPE %	FALL IN IN FEET	ACTUAL CAP. Q. CFS.	VEL. FEET PER SECOND	TIME (ENTRY: MIN)	
STREET	M.H. FROM	M.H. TO	AREA AC	R	A.R.											SECT MIN.	ACCUM MIN.
	1	2	1.82	0.35	0.64		0.64	2.85	1.82	300	10"	1.35	4.05	2.35	5.1	0.97	10.97
	2	3	2.73	0.35	0.96		1.60	2.70	4.32	260	15"	0.60	1.56	4.85	4.7	1.14	12.11
	3	4	2.57	0.35	0.90		2.50	2.55	6.38	265	18"	0.52	1.38	7.20	4.9	0.90	13.01
	4	5	2.06	0.35	0.72		3.22	2.45	7.89	306	18"	1.24	3.79	11.30	7.7	0.67	13.68
	6	7	2.63	0.35	0.92		0.92	2.85	2.62	300	12"	1.43	4.29	3.95	6.0	0.83	10.83
	7	8	-	-	-				2.62	300	12"	1.83	5.49	4.45	6.8	0.74	11.57
	8	9	3.70	0.35	1.30		2.22	2.65	5.88	345	15"	2.04	7.04	8.85	8.5	0.67	12.24
	10	11	4.46	0.35	1.56		1.56	2.85	4.45	300	15"	1.80	5.40	8.30	6.8	0.74	10.74
	11	12	1.76	0.35	0.62		2.18	2.73	5.95	275	15"	1.50	4.13	7.60	7.4	0.62	11.36
	12	13	1.05	0.35	0.37		2.55	2.68	6.83	265	15"	1.30	3.45	7.10	6.9	0.64	12.00
	5	9	1.06	0.35	0.37		3.59	2.38	8.54	265	18"	1.90	5.04	13.90	9.5	0.46	14.14
	9	13	1.32	0.35	0.46		6.27	2.33	14.61	265	18"	2.50	6.62	15.80	11.0	0.40	14.54
	13	14	5.64	0.35	1.97		10.79	2.28	24.60	500	24"	1.76	8.80	29.50	11.2	0.74	15.28
	14	15	1.37	0.35	0.48		11.27	2.24	25.24	500	27"	1.15	5.75	33.00	9.8	0.84	16.12
	15	16	5.81	0.20	1.16		12.43	2.15	26.72	110	27"	1.50	1.65	37.50	11.2	0.16	16.28
	16	outlet	-	-	-		12.43	2.15	26,72	500 CMP	33"	0,75	3.75	26,75	5.4	1.54	17.82
Oversize for major system	15	16	5.81	0.20	1.16		12.43	2.15	26.72	110	33"	1.50	1.65	65.00	12.8	0.14	16.26

TABLE 3. HYDROLOGIC SOILS GROUPS

As defined by U.S. Soil Conservation Services

A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downwards movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

TABLE 4. RUNOFF CURVE NUMBERS

Runoff curve numbers for selected agricultural, suburban, and urban land use. (Antecedent moisture condition II, and $I_a = 0.2S$)

LAND USE DESCRIPTION		HYDROLOGIC SOIL GROUP			
		A	B	C	D
Cultivated land1/: without conservation treatment		72	81	88	91
: with conservation treatment		62	71	78	81
Pasture or range land: poor condition		68	79	86	89
good condition		39	61	74	80
Meadow: good condition		30	58	71	78
Wood or Forest land: thin stand, poor cover, no mulch		45	66	77	83
good cover2/		25	55	70	77
Open Spaces, lawns, parks, golf courses, cemeteries, etc.					
good condition: grass cover on 75% or more of the area		39	61	74	80
fair condition: grass cover on 50% to 75% of the area		49	69	79	84
Commercial and business areas (85% impervious)		89	92	94	95
Industrial districts (72% impervious).		81	88	91	93
Residential:3/					
Average lot size	Average % Impervious4/				
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.5/		98	98	98	98
Streets and roads:					
paved with curbs and storm sewers5/		98	98	98	98
gravel		76	85	89	91
dirt		72	82	87	89

1/ For a more detailed description of agricultural land use curve numbers refer to National Engineering Handbook, Section 4, Hydrology, Chapter 9, Aug. 1972.

2/ Good cover is protected from grazing and litter and brush cover soil.

3/ Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

4/ The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

5/ In some warmer climates of the country a curve number of 95 may be used.

Source: U.S. Soil Conservation Services

AMC II - The average case.

AMC III - Heavy or light rainfall and low temperatures having occurred during the five previous days. This is the highest runoff potential.

Antecedent condition III is assumed prior to low frequency storms such as the 100-year storm; thus the CN value changes from 74 to 88 (Table 5). The cumulative runoff is then obtained from Figure 3.

P_{24} = 5.39 inches

Q = 4.15 inches

The time for overland flow used in establishing the time of concentration was obtained from the upland method (Figure 4) based on the overland flow distance and percent slope.

Overland flow distance	= 2,600 feet
Percent slope	= 1.5%
Average velocity (paved area)	= 2.4 ft/s
Time of concentration	= 18 min = 0.3 hour

With the time of concentration, the peak discharge in cubic feet per second per square mile per inch of runoff (CSM/inch) is read from Figure 5. The resulting peak flow for the area under investigation may then be calculated.

$$q_p = 675 \text{ CSM per inch of runoff}$$

$$q = q_p \; A \; Q = 675 \; (.06) \; 4.15$$

$$= 168.08 \text{ cfs}$$

The accuracy of this figure is not crucial because of high flow capacities available on the roadways and the allowable tolerances in flow depths.

Ratio: Major/Minor: 168.08/26.72 = 6.29

The ratio factor is used on the major storm design sheets (Table 6) to establish flows in individual sections upstream. As will be seen from the design sheet, the site will accommodate the 100-year storm subject only to enlargement of the downstream

TABLE 5. RUNOFF CURVE NUMBERS CONVERSION TABLE

Curve numbers (CN) and constants for the case $I_a = 0.2S$

1	2	3	4	5	1	2	3	4	5
CN for condition II	CN for conditions I	III	S values*	Curve* starts where P =	CN for condition II	CN for conditions I	III	S values*	Curve* starts where P =
			(inches)	(inches)				(inches)	(inches)
100	100	100	0	0	60	40	78	6.67	1.33
99	97	100	.101	.02	59	39	77	6.95	1.39
98	94	99	.204	.04	58	38	76	7.24	1.45
97	91	99	.309	.06	57	37	75	7.54	1.51
96	89	99	.417	.08	56	36	75	7.86	1.57
95	87	98	.526	.11	55	35	74	8.18	1.64
94	85	98	.638	.13	54	34	73	8.52	1.70
93	83	98	.753	.15	53	33	72	8.87	1.77
92	81	97	.870	.17	52	32	71	9.23	1.85
91	80	97	.989	.20	51	31	70	9.61	1.92
90	78	96	1.11	.22	50	31	70	10.0	2.00
89	76	96	1.24	.25	49	30	69	10.4	2.08
88	75	95	1.36	.27	48	29	68	10.8	2.16
87	73	95	1.49	.30	47	28	67	11.3	2.26
86	72	94	1.63	.33	46	27	66	11.7	2.34
85	70	94	1.76	.35	45	26	65	12.2	2.44
84	68	93	1.90	.38	44	25	64	12.7	2.54
83	67	93	2.05	.41	43	25	63	13.2	2.64
82	66	92	2.20	.44	42	24	62	13.8	2.76
81	64	92	2.34	.47	41	23	61	14.4	2.88
80	63	91	2.50	.50	40	22	60	15.0	3.00
79	62	91	2.66	.53	39	21	59	15.6	3.12
78	60	90	2.82	.56	38	21	58	16.3	3.26
77	59	89	2.99	.60	37	20	57	17.0	3.40
76	58	89	3.16	.63	36	19	56	17.8	3.56
75	57	88	3.33	.67	35	18	55	18.6	3.72
74	55	88	3.51	.70	34	18	54	19.4	3.88
73	54	87	3.70	.74	33	17	53	20.3	4.06
72	53	86	3.89	.78	32	16	52	21.2	4.24
71	52	86	4.08	.82	31	16	51	22.2	4.44
70	51	85	4.28	.86	30	15	50	23.3	4.66
69	50	84	4.49	.90					
68	48	84	4.70	.94	25	12	43	30.0	6.00
67	47	83	4.92	.98	20	9	37	40.0	8.00
66	46	82	5.15	1.03	15	6	30	56.7	11.34
65	45	82	5.38	1.08	10	4	22	90.0	18.00
64	44	81	5.62	1.12	5	2	13	190.0	38.00
63	43	80	5.87	1.17	0	0	0	infinity	infinity
62	42	79	6.13	1.23					
61	41	78	6.39	1.28					

* For CN in column 1.

Source: U.S. Soil Conservation Services

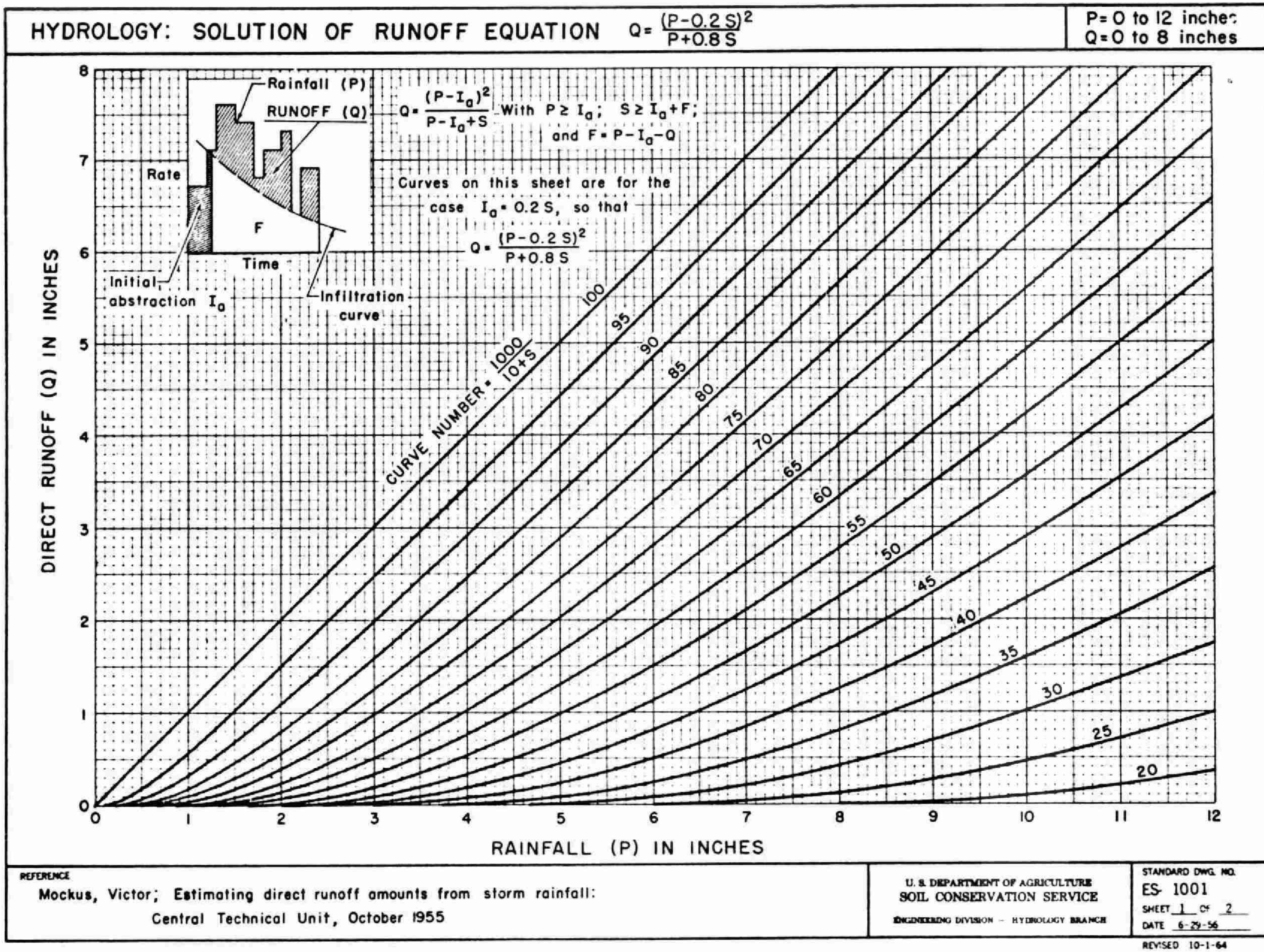


FIGURE 3. ESTIMATING DIRECT RUNOFF AMOUNTS FROM STORM RUNOFF

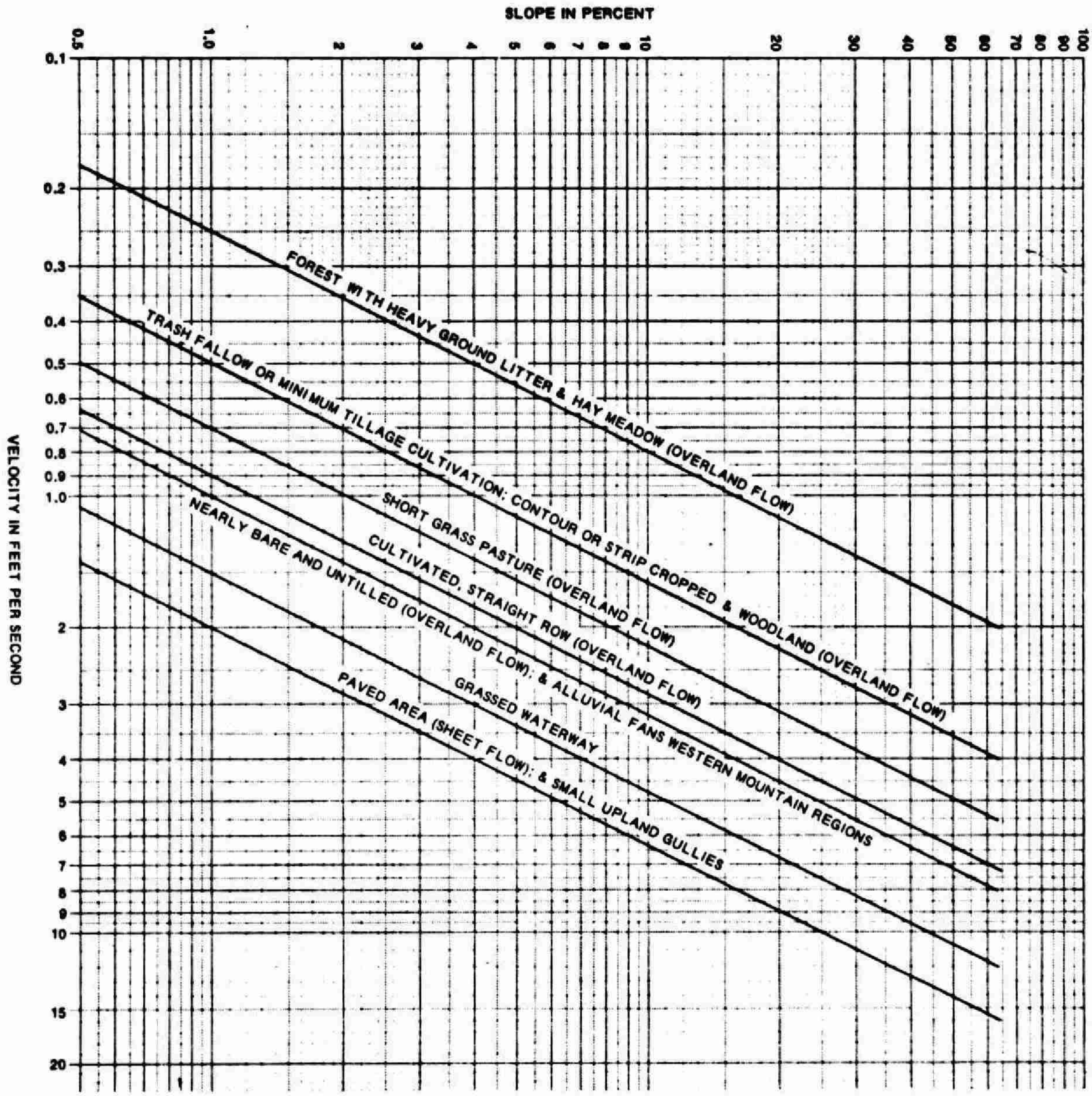


FIGURE 4. VELOCITIES FOR UPLAND METHOD OF ESTIMATING T_C

SOURCE: U.S. SOIL CONSERVATION SERVICES

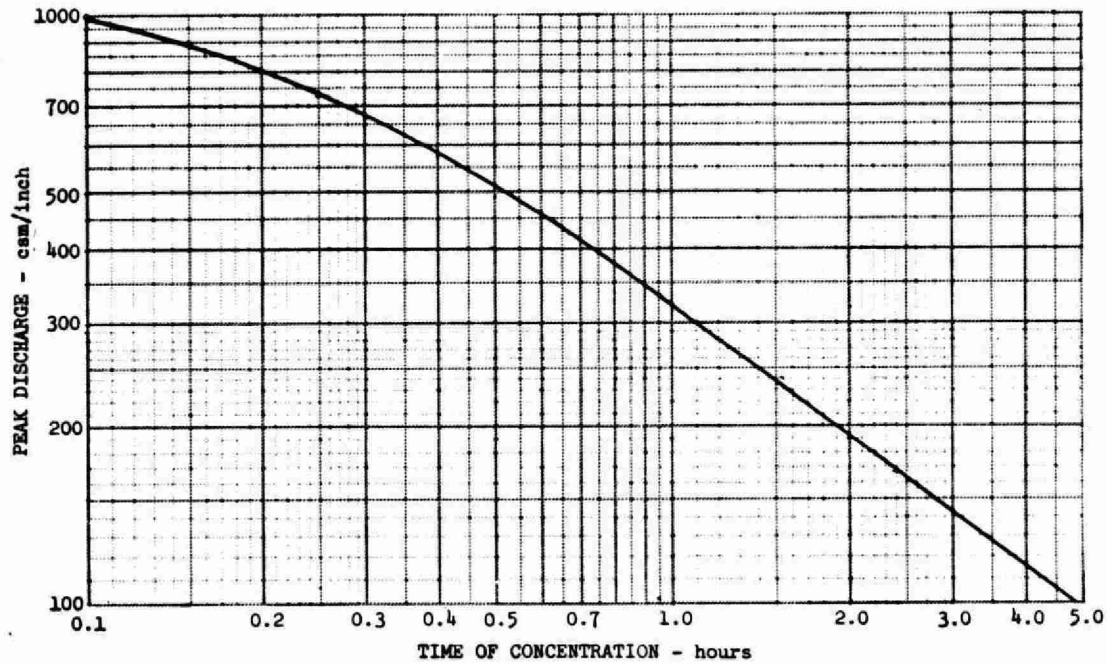


FIGURE 5. PEAK DISCHARGE IN CSM PER INCH OF RUNOFF VERSUS TIME OF CONCENTRATION (T_c) FOR 24-HOUR, TYPE II STORM DISTRIBUTION

SOURCE: U.S. SOIL CONSERVATION SERVICES

MUNICIPALITY:
SUBDIVISION NAME:

MAJOR STORM DRAINAGE SYSTEM

DESIGN STORM: 100 Year
HYDROLOGIC SOIL GROUP: B
RUNOFF CURVE NUMBER (AMC II): 74
RUNOFF CURVE NUMBER (AMC III): 88
DRAINAGE AREA AT MH. 16: 38.01

INTENSITY / Tc.:
RUNOFF DEPTH:
Q: 168.08
$\frac{Q\,major}{Q\,minor}$: $\frac{168.08}{26.72} = 6.29$

DESIGN SHEET 1 OF 1
DESIGNER P.T.A.L. DATE April, 1977

LOCATION			PIPE				Q	FACTOR	Q	SURFACE	ROAD	SURFACE	OVERSIZE
STREET	MH. FROM	MH. TO	SIZE	%	CAPACITY	SURCH. CAP.	2 yr		100 yr	FLOW	%	CAPACITY	PIPE
	1	2	10"	1.35	2.35		1.82	6.29	11.45	9.10	2.0	85.0	No
	2	3	15"	0.60	4.85		4.32	6.29	27.17	22.32	2.0	170.0	No
	3	4	18"	0.52	7.20		6.38	6.29	40.13	22.93	2.0	85.0	No
	4	5	18"	1.24	11.30		7.89	6.29	49.63	38.33	1.90	85.0	No
	6	7	12"	1.43	3.95		2.62	6.29	16.48	12.53	2.0	85.0	No
	7	8	12"	1.83	4.45		2.62	6.29	16.48	12.03	2.2	85.0	No
	8	9	15"	2.04	8.85		5.88	6.29	36.99	28.14	2.0	85.0	No
	10	11	15"	1.80	8.30		4.45	6.29	27.99	19.69	1.85	170.0	No
	11	12	15"	1.50	7.60		5.95	6.29	37.43	29.83	2.0	170.0	No
	12	13	15"	1.30	7.10		6.83	6.29	42.96	35.85	2.2	190.0	No
	5	9	18"	1.90	13.90		8.54	6.29	53.72	39.82	2.0	150.0	No
	9	13	18"	2.50	15.80		14.61	6.29	91.90	76.1	2.0	150.0	No
	13	14	24"	1.76	29.50		24.60	6.29	154.73	125.23	2.5	140.0	No
	14	15	27"	1.15	33.00		25.24	6.29	158.76	125.76	2.0	140.0	No
	15	16	27"	1.50	37.50		26.72	6.29	168.07	130.57	1.60	115.0	Yes
	15	16	33"	1.50	65.00		26.72	6.29	168.07	103.07	1.60	115.0	No
	16	outlet	33" CMP	0.75	26.75		26.72	6.29	168.07	141.32	1.80	Nil	No

TABLE 6. MAJOR DESIGN SHEET

portion of the storm sewer and therefore no reduction in major storm frequency is necessary. The hydraulic capacity of the roadways are shown on Figure 6.

The minor system will be surcharged during times when the major system is operating, and as such will function as a pressure system. The additional capacity of the minor system can be determined by using Hazen-Williams formula and allowing for the headlosses in the system. Since the additional capacity often has only a minor effect on the overall capacity of the minor and major system, it has been ignored in this example.

Foundation Drains

To establish the groundwater level, piezometer measurements over a 12 month period were taken, indicating the groundwater table would be safely below the footing elevations for the proposed buildings, minimizing the amount of inflow that can be expected into the foundation drains. The municipal requirements include detailed lot grading control, thus further reducing the possibility of surface water entering the foundation drains. However, since conclusive flow measurements are not presently available for foundation drains under similar conditions, the arbitrary flow of 0.0027 cfs is used. For detailed calcultion see Table 7.

Roof Top Storage

To illustrate the effect of roof top storage, the drainage for the school site adjacent to M.H.16 will be designed on the basis of using controlled flow roof drains [3].

GIVEN: Site area: 5.00 acres

Roof area: 40,000 s.f.

$$A \times R = \frac{40{,}000}{43{,}560} \times 1.0 = 0.92$$

Mass inflow curve determination

The development of the mass inflow curve for the 100-year storm followed the method used by the Engineering Research and Development Bureau, New York State Department of Transportation, Research Report 69-2.

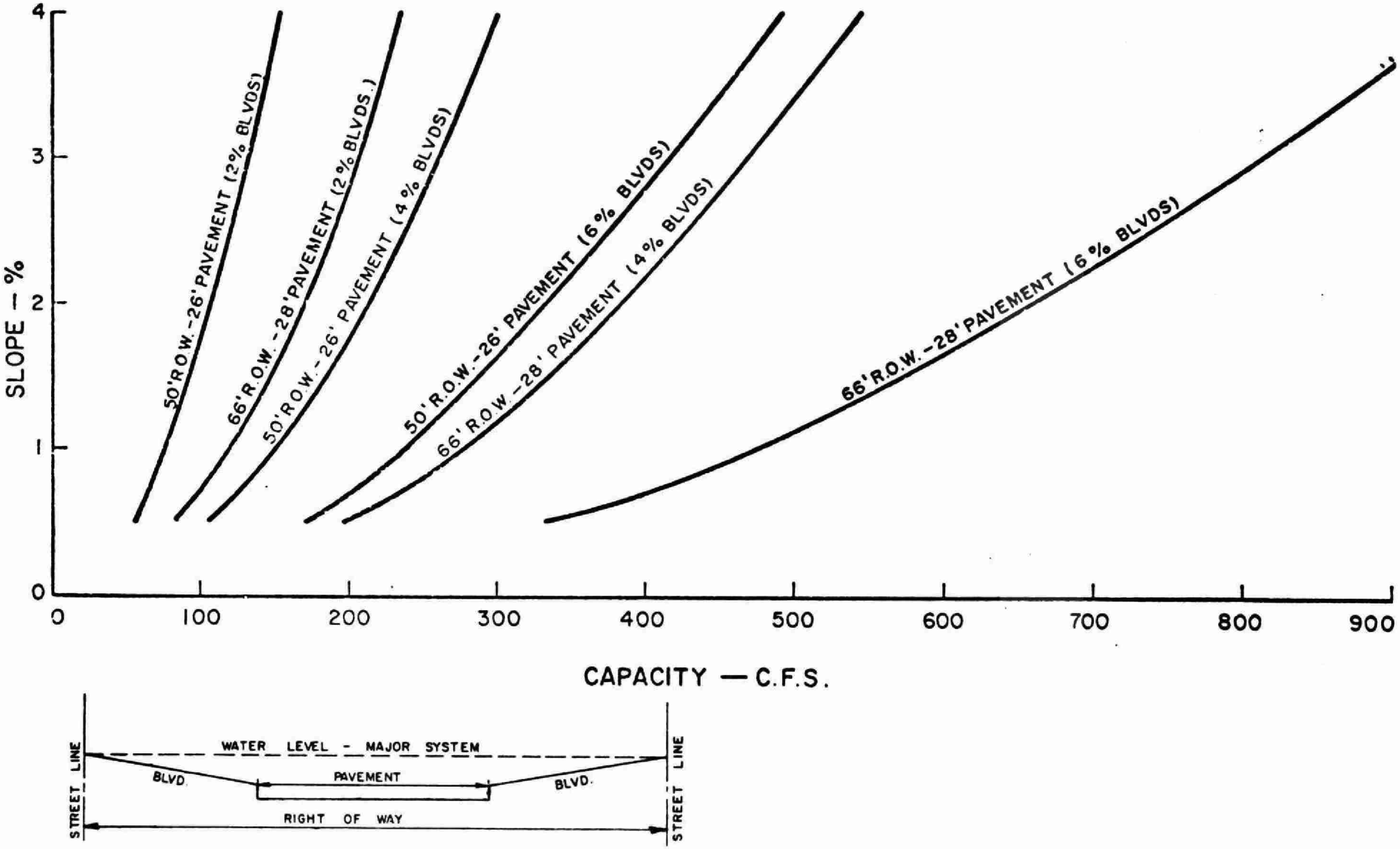


FIGURE 6. HYDRAULIC CAPACITY OF ROADWAYS

TABLE 7. FOUNDATION DRAIN COLLECTOR DESIGN SHEET

sheet no. 1 of 1 , job no. ______
project Design Example
designer P.T.A.L. , date Feb/77

LOCATION	FROM M.H.	TO M.H.	AREA AC.	UNIT DENSITY PER ACRE	TOTAL UNITS	CUM. UNITS	FLOW PER UNIT c.f.s.	TOTAL FLOW c.f.s.	LENGTH ft.	GRADIENT %	PIPE DIA. inches	CAPACITY (c.f.s.)	VELOCITY (f.p.s.)
Crescent 'G'	1A	2A	2.97	6	18	18	0.0027	0.048	390	0.98	8	1.08	3.7
"	2A	3A	1.78	6	11	29	0.0027	0.078	310	1.51	8	1.32	4.5
"	3A	4A	3.68	6	22	51	0.0027	0.138	500	0.50	8	0.76	2.6
"	4A	5A	1.48	6	9	60	0.0027	0.162	306	0.55	8	0.80	2.7
"	1A	6A	3.75	6	23	23	0.0027	0.062	500	1.39	8	1.28	4.3
"	6A	7A	2.30	6	14	37	0.0027	0.023	295	2.25	8	1.62	5.5
"	7A	8A	1.43	6	9	46	0.0027	0.124	345	1.31	8	1.24	4.2
Street 'F'	9A	10A	3.80	8	30	30	0.0027	0.081	450	1.20	8	1.19	4.0
"	10A	11A	2.10	8	17	47	0.0027	0.127	435	1.20	8	1.19	4.0
Street 'A'	5A	8A	1.56	8	13	106	0.0027	0.286	268	1.81	8	1.45	5.0
"	8A	11A	1.27	8	10	116	0.0027	0.313	245	4.34	8	2.23	7.6
"	11A	13A	2.33	8	19	135	0.0027	0.365	435	1.42	8	1.28	4.4

This method makes use of the intensity duration curves and the simple rainfall-runoff relationship Q=CIA. This method when used in combination with the Rational method should be restricted to small catchment areas, such as roof tops and parking lots, and areas should not exceed 20 acres [3].

Time min.	AR	I in./hr.	Time secs.	Volume cu. ft.
10	0.92	7.02	600	3,875
15	0.92	5.76	900	4,769
30	0.92	3.8	1800	6,293
60	0.92	2.31	3600	7,651
120	0.92	1.28	7200	8,479
360	0.92	.59	21600	11,724
720	0.92	.38	43200	15,102
1440	0.92	.22	86400	17,587

These volumes are plotted on the mass inflow-outflow diagram for roof storage (Figure 7). In order to meet the Plumbing Code, four roof drains are required for this roof area. Based on a common type of controlled flow roof drain, a flow rate of 18 gpm (U.S.) per weir is selected. Minimum outflow rate is therefore 4 x 18 gpm = 72 gpm = 0.16 cfs. This rate is plotted on the diagram (Figure 7) as mass outflow. The maximum ordinate between the two curves is scaled to be 8,700 c.f. equivalent to a maximum of 2.6 inches of depth, safely below the 7.7 inches maximum, equivalent to a 40 lb/s.f. snow load.

In order to establish the effect of this storage on the total school site, particularly as it relates to "zero increase in peak runoff", the following calculations are made:

GIVEN:	A	R	AR
Site Area:	5.00 acres		
Roof Area:	0.92 acres		
Parking, etc:	1.00 acres	0.90	0.90
Sodded Areas:	3.08 acres	0.20	0.62
			1.52

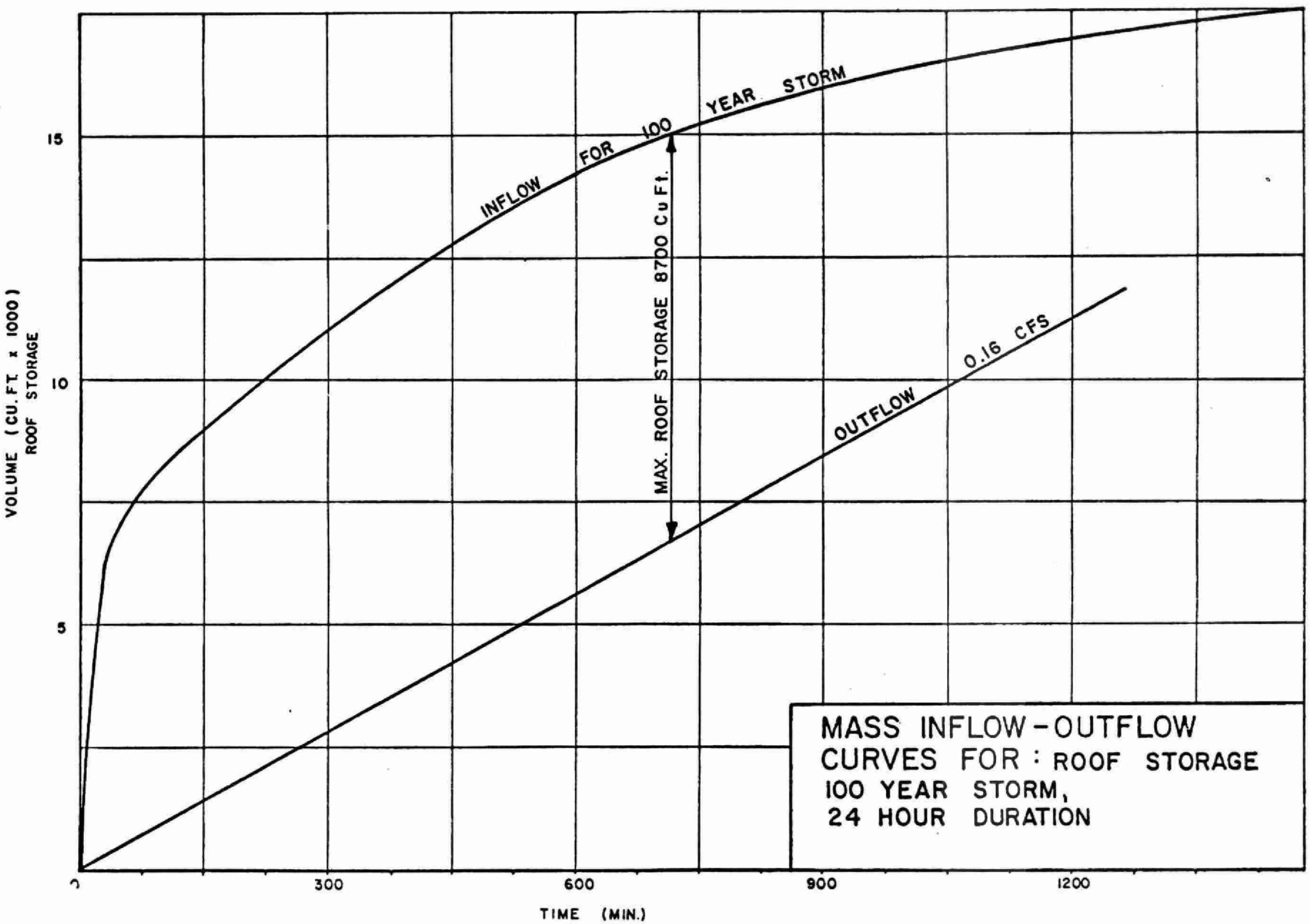


FIGURE 7. MASS INFLOW-OUTFLOW CURVES FOR ROOF STORAGE

FIND: Storage volume required to achieve zero increase in peak runoff from a 10-year storm.

Maximum release rate: = 5.0 x 0.2 x 5 in/hr.

= 5.0 cfs (10-yr. storm)

Volume calculations

TIME min.	AR	I in./hr	TIME secs.	VOLUME c.f.	ROOF DISCH. 0.16 cfs	TOTAL DISCH. c.f.	PERMITTED RELEASE
10	1.52	7.02	600	6402	96	6498	3000
15	1.52	5.76	900	7880	144	8024	6000
60	1.52	2.31	3600	12,640	576	13,216	18,000
120	1.52	1.28	7200	14,008	1152	15,160	36,000
360	1.52	0.59	21,600	19,371	3456	22,827	108,000
720	1.52	0.38	43,200	28,952	6912	31,864	216,000
1440	1.52	0.22	86,400	28,892	13,824	42,716	432,000

The total discharge volume, when compared to the equivalent discharge from a 10-year storm for predevelopment conditions, indicates a maximum storage requirement of about 3,500 cu. ft. at ten minutes. If this volume is stored on the total grassed area, the equivalent depth equals

$$\frac{3500}{3.08 \times 43{,}560} = 0.026 \text{ ft.} = 0.313 \text{ in.}$$

Since a depth of 12 to 18 inches could easily be tolerated for ponding during a 100-year storm, only a very small area need be contoured to permit ponding.

Subsurface Disposal

From soils investigations a percolation rate of 2 inches per 10 minutes has been determined for the soil in the designated greenbelt area adjacent to M.H.16.

Since subsurface disposal of storm water is very beneficial not only for groundwater recharge but also as a means to reduce the rate of runoff, the outlet section of the storm sewer will be designed for subsurface disposal, using a perforated pipe surrounded by a stone filter as shown in detail on Figure 8. Since clogging of the filter is a

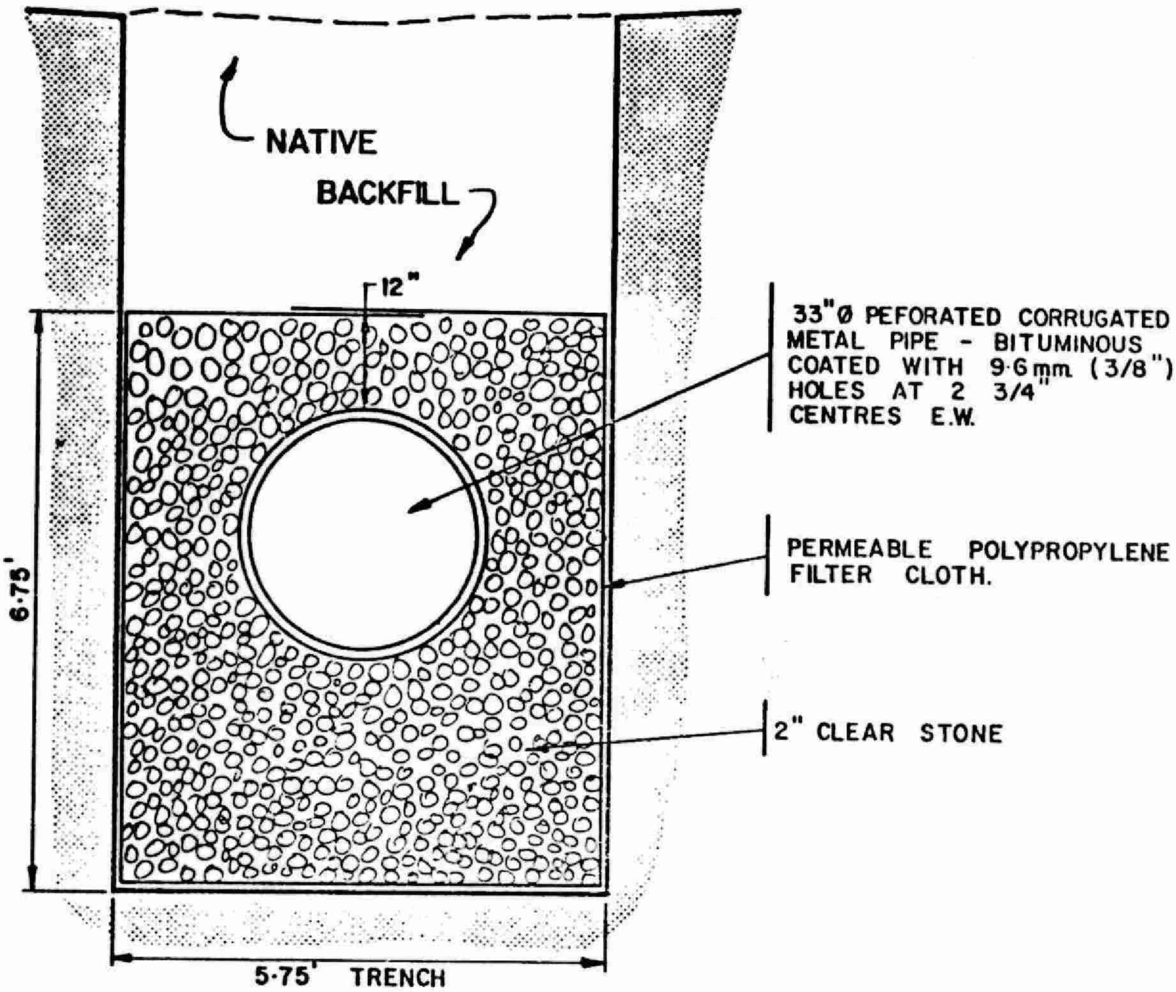


FIGURE 8. PERFORATED STORM SEWER FOR SUBSURFACE DISPOSAL

potential risk over a length of time, no reduction in pipe size will be made, permitting the pipe to act as a solid pipe in any event.

Calculations

Trench length:	500 ft.
Trench width:	5.75 ft.
Trench depth:	6.75 ft. (below top of pipe)
Pipe diameter:	33"
Pipe area:	5.94 sq. ft.
Stone area:	5.75 x 6.75 - 5.94 = 32.87 s.f.
Stone size:	2" clear crushed
Stone voids:	40%
Storage volume:	(0.40 x 32.87 + 5.94) x 500 = 9545 cu. ft.
Infiltration (10 mins)	Trench area x 2 inches = 5.75 x 500 x $\frac{2}{12}$ = 479.17 cu. ft.
Infiltration Rate:	.80 cfs

STORAGE ANALYSIS

The design example is based on the "zero increase in runoff" concept, which for this example has been defined as controlling the outflow from the development to the equivalent rate of a 10-year storm from an undeveloped area. For a T_c of 18.00 minutes for overland flow, the 10-year intensity is 3.85 inches per hour.

Maximum outflow permitted: 38.01 acres x 0.20 x 3.85 = 29.27 cfs

The Soil Conservation Service has developed two charts which provide a quick and approximate method of determining storage requirements. Figure 9 is applicable in designs with pipe drop inlets of 0 to 300 CSM release rate and weir flow structure 0 to 5 CSM. Figure 10 is applied in cases where the previous criteria are exceeded. The accuracy of Figure 9 is within 5% for release rates under 100 CSM and within 10% for release rates over 100 CSM. Figure 10 will produce results up to 25% too high where runoff curve values are less than 65 along with short time of concentration. Values up to 25% too low will result with curve numbers over 85 and long time of concentration.

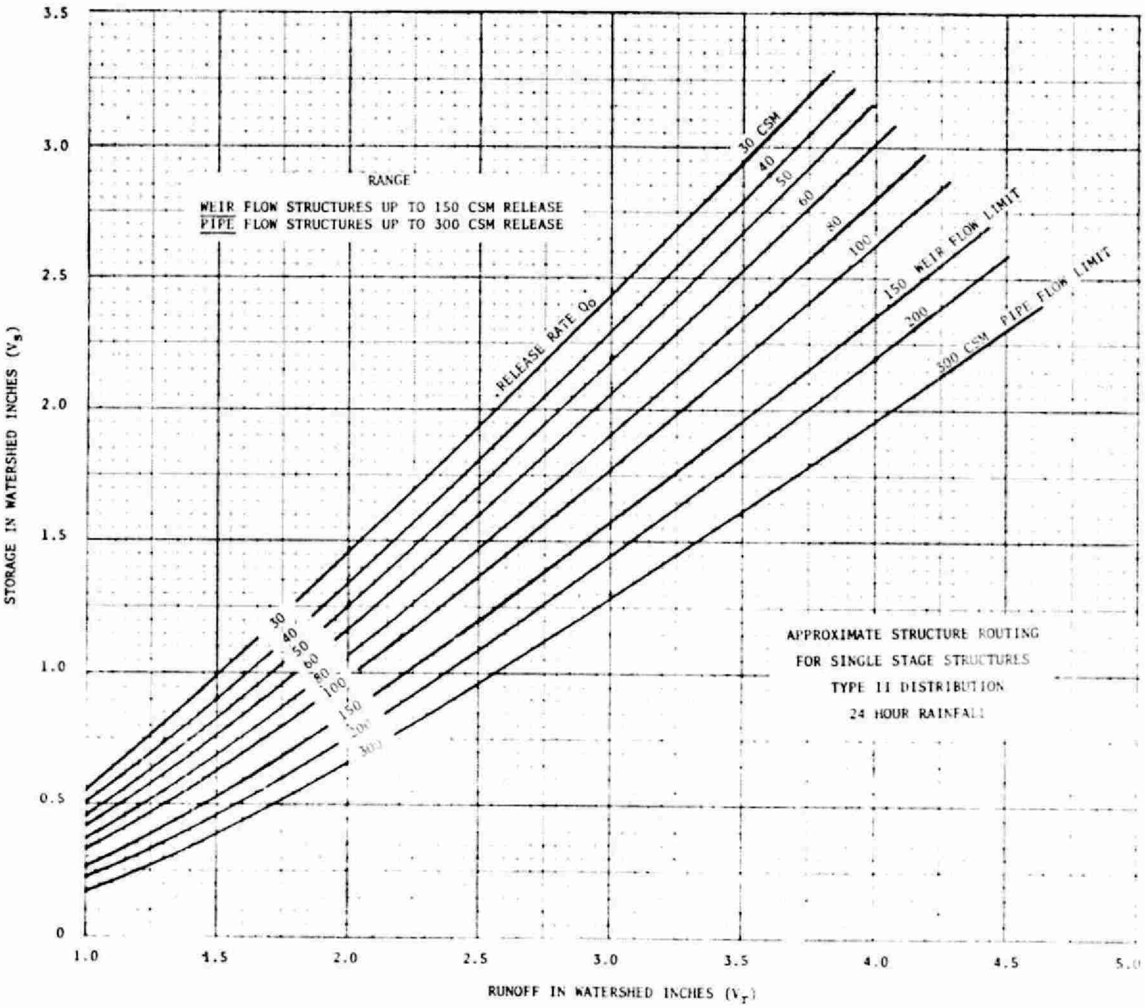


FIGURE 9. APPROXIMATE SINGLE-STAGE STRUCTURE ROUTING FOR WEIR FLOW STRUCTURES UP TO 150 CSM RELEASE RATE AND PIPE FLOW STRUCTURES UP TO 300 CSM RELEASE RATE.

SOURCE: U.S. SOIL CONSERVATION SERVICES

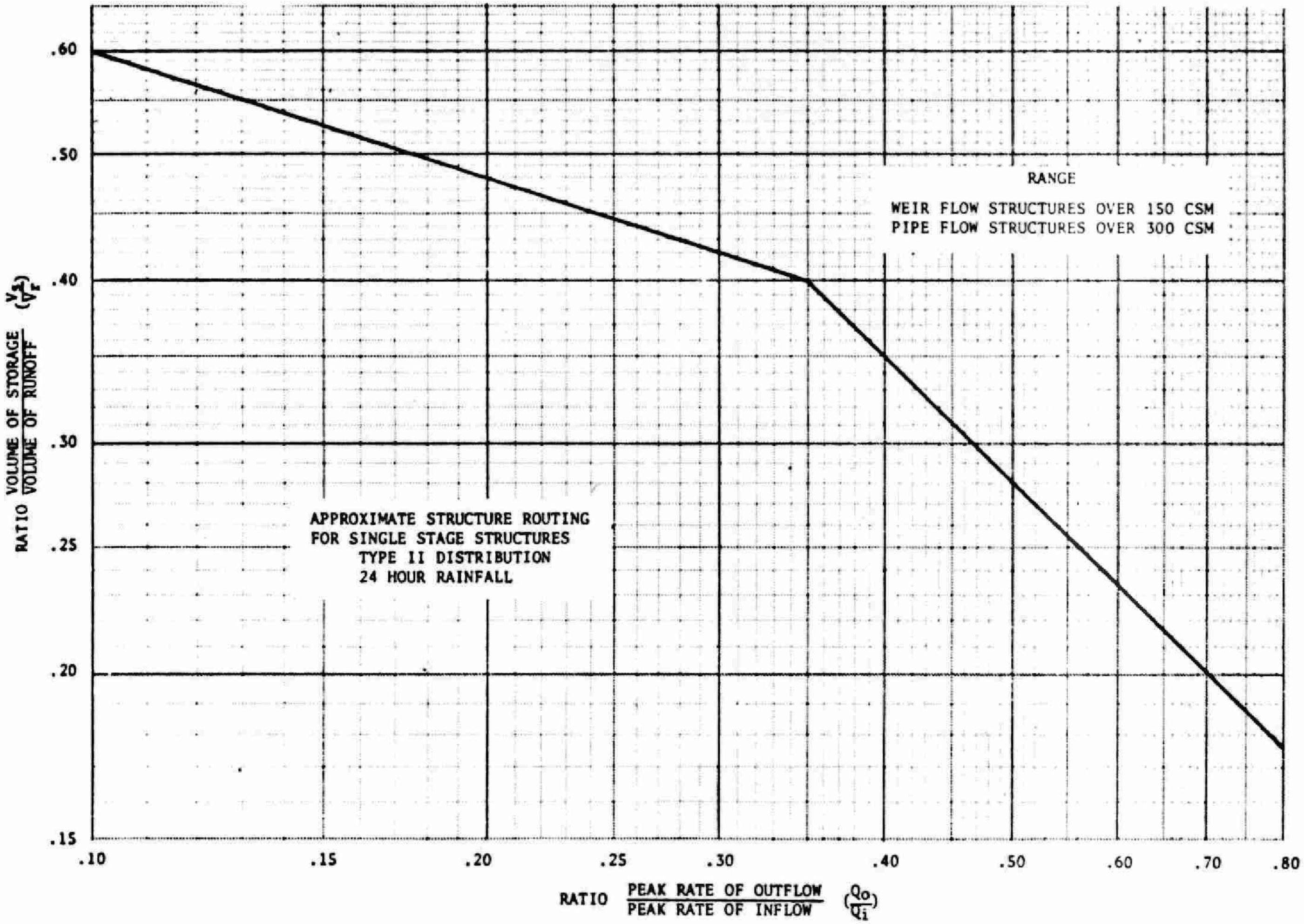


FIGURE 10. APPROXIMATE SINGLE-STAGE STRUCTURE ROUTING FOR WEIR FLOW STRUCTURES OVER 150 CSM RELEASE RATE AND PIPE FLOW STRUCTURES OVER 300 CSM RELEASE RATE

SOURCE : U.S. SOIL CONSERVATION SERVICES

To use the charts the design storm peak flow, the allowable outflow and the control outlet should be determined.

In the design example, the peak flow created by the 100-year storm of 168.08 cfs is to be limited to 29.27 cfs by use of a storage facility with a pipe control outlet.

GIVEN: Q_o = 29.27 cfs (allowable peak outflow)

Q_i = 168.08 cfs (peak inflow)

V_r = 4.15 inches (inflow runoff)

Selection of Figure

$$Q_o = \frac{29.27}{0.06 \text{ MI}^2} \text{ cfs} = 487.83 \text{ CSM}$$

Since Q_o is greater than 300 CSM, use Figure 10,

$$\frac{Q_o}{Q_1} = \frac{29.27}{168.08} = 0.174$$

Corresponding to $\frac{Q_o}{Q_1} = 0.17$ $\frac{V_s}{V_r} = 0.5$

V_r = 4.15 inches

$$V_s = \frac{0.5 \times 4.15 \text{ (in)} \times 38.01 \text{ (acres)} \times 43560 \text{ (ft/acre)}}{12 \text{ (in/ft)}}$$

$= 286{,}300$ cu. ft.

Since the perforated pipe has a storage capacity of 9545 cu. ft. and an exfiltration capacity of 69.120 cu. ft. (based on 0.80 cfs over the 24 hour period), the surface storage requirement will be reduced by 78,665 cu. ft. to 207,635 cu. ft.

This storage volume, which is only required for the 100-year storm, can most economically be obtained by contouring the greenbelt area to create a detention area with a controlled outflow. Assuming an average depth of three feet, the area required will be about 1.59 acres.

COST COMPARISON

The techniques used in this design example have been used in recent developments in Ontario. In addition to the obvious technical advantages when compared with conventional servicing methods, cost

savings are also obtainable. The following describes the items for which cost savings have resulted.

Minor-Major Drainage Concept

This concept, if allowed for in the planning stages will usually avoid sewers being installed against grades, thus avoiding deep sewers. Since foundation drains are not connected to the minor system, storm sewers need not be extended beyond the last upstream catch basins, thus saving in sewer length, particularly in areas with cul-de-sacs and crescents. For the same reason, the storm sewer need not be installed at depths to accommodate foundation drains but only sufficiently below the surface to be protected against frost damage. This separation in depth between storm and sanitary sewer will result in shallower sanitary sewers as well, since depth adjustments to permit crossover of the two pipes will occur less frequently.

Considerable saving in road construction will also occur since trench settlements, particularly in clay areas, will be greatly reduced due to the shallow depth of storm sewers.

A significant saving also results from using a lower rainfall intensity curve, i.e. 2-year versus 10-year, now possible since backup in foundation drains is no longer a concern.

Foundation Drain Collector

As an additional pipe, the separate foundation drain collector will be an extra cost when compared to conventional systems. Since the FDC is installed in a common trench and at generally the same depth as the sanitary sewer, excavation, bedding and backfilling costs are not significant. Only the pipe material, cost of laying and the manholes or clean outs required are additional costs.

Service Connections

Since roofwater leaders are not ordinarily connected to the storm sewer, a service trench has been eliminated. This design utilizes only one trench for both sanitary and foundation connections, each serving two units where possible.

Cost Summary

As an indication of the cost comparison between an F.D.C. system and a conventional system, the following example represents an actual project built in 1976.

CONSTRUCTION COST PER LOT (Single family and semi-detached)

	Conventional	F.D.C. System
1. Sanitary Sewer	$ 320.65	
1a. Sanitary Sewer + F.D.C.		$ 405.84
2. Sanitary Manholes	$ 145.69	
2a. Sanitary + F.D.C. Manholes		$ 273.87
3. Storm Sewer	$ 962.08	$ 485.62
4. Storm Manholes	$ 154.03	$ 93.68
5. Connections		
a) Within Road Allowance	$ 247.19	$ 212.02
b) On lots	$ 420.00	$ 351.00
TOTALS:	$2213.64	$1822.04
Saving: $2213.64 - $1822.04 =	$ 391.60	
Eng. & Cont.	58.74	
TOTAL SAVING PER LOT	$ 450.34	

An analysis of the total effect of using the method described in this design example as compared to conventional design, generally applied in the greater Toronto area, has shown total savings on all the underground drainage facilities from individual dwellings to the downstream limit of the subdivision of 30% or greater. If downstream drainage facilities are considered as well, the effect of reduced runoff will result in further savings even more significant.

MANUAL DESIGN METHODS AND COMPUTER MODELLING

Hydrologic analyses for urban areas have been based, since the turn of the century, almost exclusively on the "Rational formula", which can only estimate peak flow. Although it is a very simple method, it has, nevertheless, given reasonable results in terms of sizing storm sewers, particularly for small areas. Various modifications have been made to the formula to permit construction of a hydrograph and a mass-inflow-

outflow graph showing detention requirements, which are necessary in modern storm water management concepts.

Of the various other manual methods available, the Soil Conservation Service's method has been used extensively for larger watersheds, and more recently has gained wider acceptance for small urban watersheds as well. Since it is based on actual flow measurements from almost any combination of conditions, such as topography, soil classification, vegetation etc., its reliability has been found to be good.

In recent years several computer models have been developed which can simulate the effects of runoff throughout a sewer system, both in terms of quantity and quality. Such simulation is based on extensive calibration which will have to be carried out for varying local conditions. In spite of the many models available, some of them very elaborate, only one model to my knowledge can simulate the condition that applies to both the minor and major systems when the major system is operating. Neither do the models, as yet, incorporate for the effect of storms moving up or down a watershed, which can be a significant factor in flood estimates.

It is important to recognize that computer models have limitations in spite of the optimistic claims of the model builders [7]. More useful models will, no doubt, be available as the model builders become more familiar with all the practical aspects of drainage systems, particularly the presence of the minor and major drainage systems.

For the design of the minor (convenience) system, the degree of accuracy is not that important. Assuming one or more of the pipes in the system should actually have been one size larger or smaller to accommodate the desired storm frequency; and recognizing that the resulting variations in capacity from one pipe size to the next is usually from 30% to 50%, the effect will be that instead of having capacity for say a two-year average storm, the sewer may turn out to have a capacity closer to a one-year or five-year storm, which is a reasonable variation for a convenience system.

A much more important fact to recognize is the presence of the major system. This is where the Rational method should be replaced by other methods, particularly to allow for the increase in runoff due to the antecedent moisture condition. However, even for the major system

there is quite some tolerance. A small increase in depth of surface flow will drastically increase the capacity of the surface routes, without necessarily causing serious flooding problems.

DESIGN STANDARDS, POLICIES AND PROCEDURES

It would be unreasonable to expect that one set of standards could be derived which in all instances would give the optimum solution in terms of level of service and cost.

Factors such as land use and densities, topography, soil conditions and vegetation vary even within a given municipality. Where standards are selected they must not be so restrictive as to prevent technological advances; indeed we recommend all municipal engineering standards be prefaced with the following clause:

> "These standards shall not be considered as a rigid requirement where variation will achieve a better technical and/or economical solution. Indeed, it is encouraged that consulting engineers continuously seek new and better solutions" [8].

It is suggested that each municipality adopt a policy on storm water management which will recognize the importance of protection against flooding, economies of construction, and protection of the environment [9]. To achieve this, we recommend the following:

a) A functional storm drainage report be undertaken prior to preparation of a draft plan. The functional report must consider the limitations and constraints external to the site, internal and external drainage patterns, and external traffic considerations which will influence street patterns - thus the "major drainage system". The engineer must work closely with the planner during the preparation of the draft plan so that street patterns are set to complement the drainage system where possible. The consulting engineer should also include in the functional report the methods he proposes to reduce storm water runoff. It should be evident that no draft plan should be reviewed by a municipal planning department prior to receipt of the functional drainage report.

Where actual submissions of detailed engineering designs are made following draft approval, the functional drainage report will have established the basic criteria to be followed, which should greatly assist in expediting approval.

b) The detailed design must recognize the importance of directing roof water to grassed areas before it is allowed to enter a storm sewer. Only for sites with a high ratio of roof area to grassed area should roof connections be considered.

c) To prevent structural damage to basements, which will occur if foundation drains are connected by gravity to storm sewers with insufficient capacity to handle major storms without surcharge above the level of basement floors, the following policy should be adopted:

- Foundation drains must not be connected to storm sewers by gravity, unless the hydraulic gradient for a regional storm will not be more than six inches above basement floors.

- Foundation drains may be connected to sanitary sewers only when the footing elevations will be above the ground water elevation and where lot grading control is adequately exercised and splash pads are utilized for downspout discharge to ground.

- In all other cases, either sump pumps or a separate foundation drain collector system should be considered.

CONCLUSIONS

The design techniques demonstrated in this example will greatly reduce, if not eliminate, most of the problems inherent in the more conventional methods being used to-day in most Canadian municipalities. The advantages can be summarized as:

a) <u>decrease</u> in peak runoffs, minimizing the effect of erosion of streams and sedimentation in lakes;

b) recharge of rainwater to the soil, approaching the condition prior to development, without major disturbance to existing vegetation;

c) protection against flood damage to basements, even for major storms;

d) maintenance of base flows in streams, preventing damage to aquatic life;

e) cost savings exceeding 30% of the cost of conventional servicing methods;

f) reduction of storm water pollution in receiving streams.

The benefits of the concepts described herein are so great that steps should be taken immediately by consultants as well as municipal, provincial and federal agencies to change their present policies. Until this happens, problems within one or more of the six major items listed above will continue, to the detriment of the public.

The challenge is there! Are you ready to change your approach and encourage others to follow?

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URBAN DRAINAGE PRACTICES IN CANADA

K.W. Moore,
Gore and Storrie Limited

INVESTIGATIONS

Much of the information on current urban drainage practices in Canada was assembled from two projects undertaken for Fisheries and Environment Canada.

Replies to a questionnaire sent to the regional offices across Canada by the Environmental Protection Service of Fisheries and Environment Canada have been assembled and summarized. Responses were incomplete from all provinces and supplemental information was obtained where possible from alternate sources.

An investigation has also been made of problems of combined and partly combined sewers in Ontario for the Urban Drainage Subcommittee of the Canada-Ontario Agreement. A 77 percent response was received from 245 Ontario municipalities.

From these investigations, a general concept was obtained with respect to current practices in the various provinces. It is the purpose of this paper to look at these practices across Canada and project the trend of thinking for the future. This will be related to the general trends for urban drainage and storm water management in the United States and Europe.

Background Statistics

In order to give some feeling of relativity to the extent of the subject as it applies across the country, two tables of statistics are given on the following pages.

Table 1 shows area and population figures and percentage of population in municipalities of over 5,000 people. The distribution of lower tier or single government municipalities of various sizes is also shown. This information is derived from Canada Census figures.

Table 2 shows statistics on the extent of service by sanitary sewer system - combined, partly combined or separated. These figures have been derived from information published by Water Pollution Control magazine.

TABLE 1. BACKGROUND STATISTICS (Derived from 1971 Census)

Province	Area in 1000 Sq.m.	Population in Thousands	Population Densities Pers/Sq.m.	Population in Municipalities over 5,000 in Thousands	Percentage of Population in Municipalities over 5,000
Newfoundland & Labrador	143.5	522.1	3.64	166.5	31.9
Prince Edward Island	2.2	111.6	51.08	28.6	25.6
Nova Scotia	20.4	789.0	38.67	713.9	90.5
New Brunswick	27.6	634.6	22.96	605.9	95.5
Quebec	524.3	6,027.8	11.50	4,170.5	69.2
Ontario	354.2	7,703.1	21.15	6,501.6	84.4
Manitoba	211.5	988.2	4.67	678.7	68.7
Saskatchewan	220.1	926.2	4.21	391.1	42.2
Alberta	246.4	1,627.9	6.61	1,264.6	77.7
British Columbia	344.8	2,184.6	6.34	1,745.6	79.9
Yukon & N.W. Territories	1548.8	53.2	6.03	17.3	32.6
CANADA TOTAL	3560.2*	21,568.3	6.06 Av	16,284.4	75.5 Av

	Number of Lower Tier+ Municipalities						
Province	Greater Than 250,000 Population	100,000 to 250,000	25,000 to 100,000	10,000 to 25,000	5,000 to 10,000	Less Than 5,000	Total
Newfoundland & Labrador	--	--	2	--	9	217	228
Prince Edward Island	--	--	--	1	1	99	101
Nova Scotia	--	1	2	14	27	50	94
New Brunswick	--	--	2	5	10	251	268
Quebec	1	2	28	54	60	1,457	1,602
Ontario	6	8	28	44	89	688	863
Manitoba	--	1	6	6	13	205	231
Saskatchewan	--	2	2	3	3	815	825
Alberta	2	--	4	8	30	338	382
British Columbia	1	1	12	30	25	135	204
Yukon & N.W. Territories	--	--	--	1	1	11	13
CANADA TOTAL	10	15	86	166	268	4,266	4,811

* Provincial land area totals do not add up to the total for Canada

NOTE: The 1976 Canada census population is 22,598,600 for an average annual growth from 1971 to 1976 of 0.94 per cent. In comparison over the same 5-year period, the fastest growing provinces are respectively: Alberta with 2.03%, British Columbia with 1.95% and Ontario with 1.09%. Saskatchewan declined by 0.41% and Manitoba and Quebec grew slowest with respectively 0.36 and 0.37 per cent.

+ Upper Tier and Lower Tier refers to levels of municipal government e.g. Upper Tier - metropolitan or regional level of government

TABLE 2. SANITARY SEWER SERVICE STATISTICS

A - LEVEL OF SERVICE

Provinces	Total Number of Lower Tier Municipalities	Number of Municipalities Served	Percentage of Number of Municipalities Served	1975 Total Population in Thousands	1975 Population Served in Thousands	Percentage of Population Served
Newfoundland & Labrador	228	37	16	543.5	247.7	46
Prince Edward Island	101	6	6	115.3	43.8	38
Nova Scotia	94	42	45	807.4	318.3	39
New Brunswick	268	38	14	658.5	296.6	45
Quebec	1,602	270	17	6,119.1	4,802.4	78
Ontario	863	307	36	8,045.0	6,155.9	76
Manitoba	231	122	53	1,002.5	761.8	76
Saskatchewan	825	66	8	911.4	524.4	58
Alberta	382	87	23	1,764.2	1,265.4	72
British Columbia	204	82	40	2,360.4	1,716.9	73
Yukon & N.W. Territories	13	4	31	61.4	17.6	29
CANADA TOTAL	4,811	1,061	22	22,388.7	16,150.8	72.1

B - DISTRIBUTION OF TYPES OF SANITARY SEWERS

Province	Percentage of Sewer Length		Percentage of Overall Provincial Population	
	Combined and Partly Combined	Separate	Combined and Partly Combined	Separate
Newfoundland & Labrador	31	69	14	32
Prince Edward Island	36	64	14	24
Nova Scotia	28	72	11	28
New Brunswick	43	57	19	26
Quebec	37	63	29	49
Ontario	25	75	19	57
Manitoba	37	63	28	48
Saskatchewan	14	86	8	50
Alberta	20	80	14	58
British Columbia	17	83	13	60
Yukon & N.W. Territories	8	92	2	27
CANADA TOTAL	28	72	20	52

NEW SEWER SYSTEM DESIGNS

Background

The desire and necessity to take concrete steps to stop the deterioration of the environment focused initial emphasis on improving the quality of domestic and industrial wastes which were being discharged to the most convenient receiving water. Much time, effort and money has been expended in this direction and encouraging results are now being achieved.

Prior to this focus on the environment and the consequent upsurge in the construction of waste treatment facilities, disposal of surface water runoff and domestic and industrial wastes was made, untreated to the nearest receiving water. In most instances both were discharged to the same receiving water by means of a single sewer pipe. This situation pertains to many older and larger municipalities where the core area of the city is serviced with combined sewers. Of the municipalities responding to the survey for combined sewers in Ontario, 40 percent replied that they had combined sewers in their system.

With the advent of sewage treatment plant construction and continual pressure over the years to improve operational efficiency and economy it became desirable to eliminate extraneous water from flows through the treatment plant. Construction of new separate storm sewers was commenced in areas having combined sewer systems in order to reduce or eliminate combined sewer overflows during times of storm.

This philosophy has been generally accepted over the years since World War II and the rapid urban expansion during these years has seen new areas of development served by these separate systems of sewers.

In many places these separate sewer systems are extensions of the original core area combined sewers. A typical example of this is the City of Cornwall where urban development outside of the original municipal boundaries was serviced by the installation of a separate sewer system by the Township. When these areas became annexed into the City, the flows from the separate system were carried by the original combined sewers. This problem is now under review by the City and the new techniques and mathematical models will be utilized to attempt to arrive at the optimum solution.

Over the years the trend has been to remove storm water from surfaces in urban areas as quickly as possible. This has led to the installation of larger and larger sewer pipes with increasing costs and also to increasing problems in downstream receiving waters due to erosion and contamination.

Recent Concerns

Research and investigation in recent years has shown that urban storm water runoff is not as harmless to natural receiving waters as had been previously assumed. The question then arises - if it is going to become necessary to provide some form of removal of contaminants from storm water runoff prior to discharge to receiving waters, what form of treatment is required, where is this most economically done and is the separation of sewers still a viable solution to the problem? There are a variety of answers to this question which are highly influenced by conditions in various local areas and unanimity may be very difficult to achieve. One response is to question the validity of storm water treatment as a basic assumption. This philosophy seems to have some favour particularly in some of the larger maritime cities where both untreated sanitary sewage and storm water runoff are discharged directly to the sea. Nevertheless, there is an increasing cognizance of the problems caused from storm water runoff and growing concern to find optimum solutions.

New Designs

Separate sewer systems

Separate sanitary and storm sewer systems are most favoured at the present time for new areas of development. In some locations where a large portion of the municipality is presently served by combined sewers, it is not considered to be of sufficient advantage to generally provide separated systems for extensions into new developments unless there is a specific reason for this to be done, e.g. to prevent or relieve overloading of existing sewers.

Runoff quantity and quality

Runoff quantity has been the accepted basis for storm sewer design in the past and, in most of the provinces, is still the only

consideration. Current literature and local, national and international conferences, however, have brought to the fore the growing concerns with respect to quality of runoff.

The Ontario Ministry of the Environment, for example, has taken a lead in directing that, within the Regional Municipality of Ottawa-Carleton, the Rideau River and its tributaries could no longer be subjected to further pollutional loads and therefore each new storm sewer outfall "will require a report on the effect of storm drainage on the water course and the method of control". This requirement has been made because of the particular sensitivity of the Rideau River to changes in the surrounding environment due to planned and projected development.

The City of Winnipeg, Manitoba has also shown concern by adopting a report on "Stormwater Management by Use of Impoundments" and by development of a "Drainage Criteria Manual for the City of Winnipeg". The latter manual was prepared in 1974 and takes into consideration the current technology for storm water management.

Alberta Environment has prepared and published in 1976 its "Objectives for Stormwater Management" for consideration by all controlling agencies, when new or proposed development is expected in order to "ensure the protection and rights of the downstream user against abnormal conditions created by storm water discharge from uncontrolled developments".

Other provinces have shown varied degrees of interest with limited studies and research being undertaken. To some extent this interest may be related to amount of funds available and subsidies provided by higher levels of government.

Design methods

The Rational method for storm sewer design, introduced in 1889, has been, and still is, the most widely used method in Canada for calculating storm water runoff. It is highly dependent on the experience and judgement of the designer and his familiarity with the local area to be able to adequately select a surface runoff coefficient and to calculate a reasonable inlet time. Rainfall intensity-duration-frequency curves are required for the area under consideration and these are usually

obtained from local observation or from published data or both. On occasion, curves are extrapolated using Gumbel probability to obtain frequences of once in 50 years or once in 100 years.

Frequency curves for once in two years or once in five years are most often used for design. This is sometimes increased to once in 10 years for commercial and industrial areas. Enclosed conduits for water courses may be designed for frequencies of once in 25 years or once in 100 years. For open water courses where flood protection is critical a frequency of occurrence of once in 100 years is used unless a "regional" storm of greater intensity has been recorded in the area.

There is frequently a lack of uniformity of approach with respect to design methods and policies adopted by the various branches of government which leads to much confusion for the designer seeking approvals.

In 1957, Kiefer and Chu* developed a method for calculating a synthetic storm hyetograph from the rainfall intensity-duration curves normally used for design in the Rational method. From this a further methodology was developed to transform the hyetograph into the sewer flow hydrograph for a typical unit drainage area. This method is used on occasion by some designers and is recently finding more favour as a means of developing hydrographs for use in the mathematical simulation models now coming into use.

A unit hydrograph method correlating characteristics of measured sewer outflow hydrographs to synthetic unit hydrographs has been used in a few municipalities. It is understood that unit hydrographs have been developed for design for Halifax, Nova Scotia and for Granby, Quebec.

The new mathematical simulation models are now receiving more attention by some designers. A number of models have been developed of varying complexity but STORM, SWMM and WRE seem to be more favoured than others in Canada. This is partly due to the research and development work supported by both Canada and the United States and partly due to their availability from these governments on a non-proprietary basis. A

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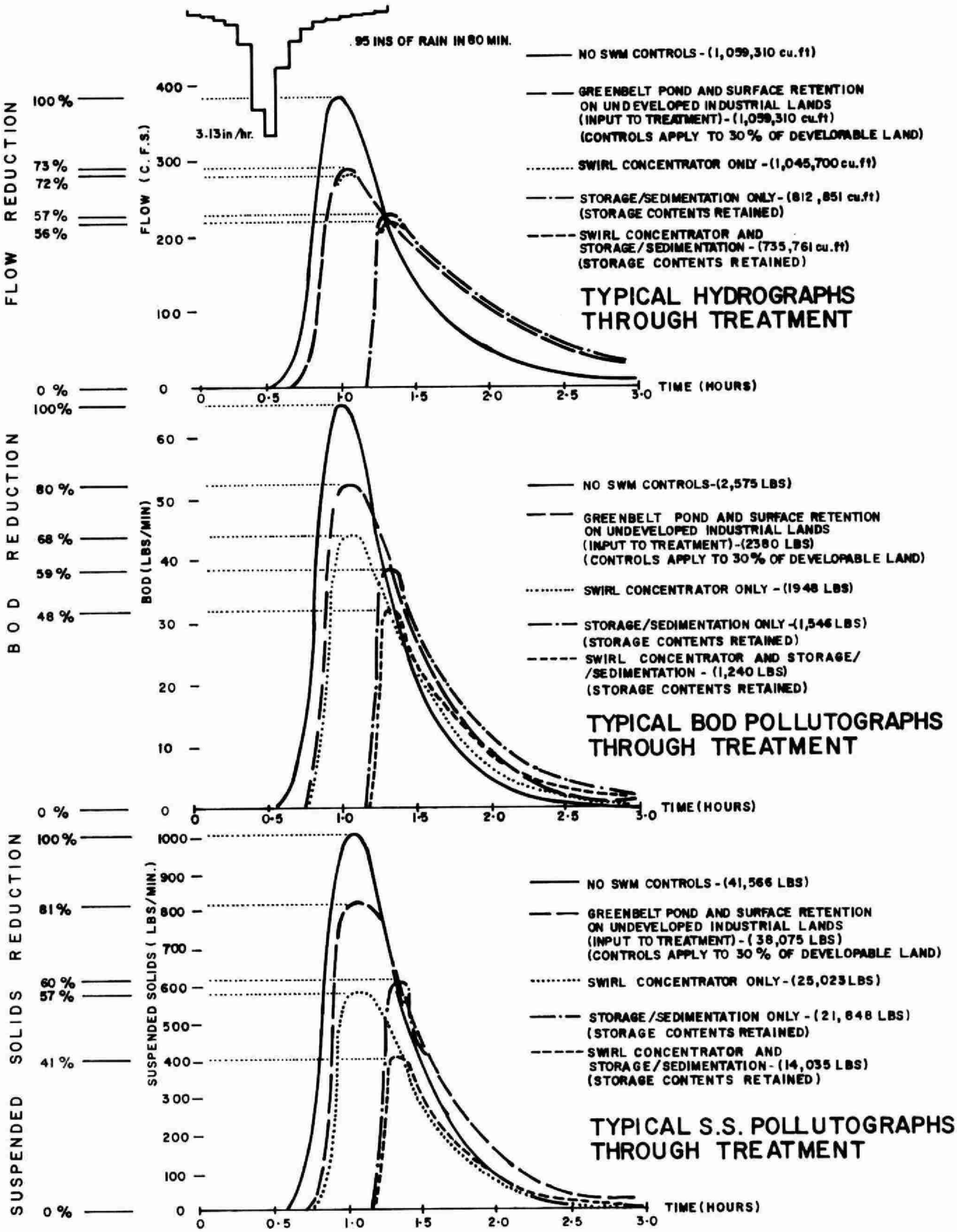
* "Synthetic Storm Pattern for Drainage Design", C.J. Kiefer and H.H. Chu, Proceedings ASCE Paper 1332, August 1957.



.95 INS OF RAIN IN 60 MIN.
3.13 in/hr.
FLOW REDUCTION
100 %
73 %
72 %
57 %
56 %
0 %
FLOW (C.F.S.)
NO SWM CONTROLS - (1,059,310 cu.ft)
GREENBELT POND AND SURFACE RETENTION ON UNDEVELOPED INDUSTRIAL LANDS (INPUT TO TREATMENT) - (1,059,310 cu.ft) (CONTROLS APPLY TO 30% OF DEVELOPABLE LAND)
SWIRL CONCENTRATOR ONLY - (1,045,700 cu.ft)
STORAGE/SEDIMENTATION ONLY - (812,851 cu.ft) (STORAGE CONTENTS RETAINED)
SWIRL CONCENTRATOR AND STORAGE/SEDIMENTATION - (735,761 cu.ft) (STORAGE CONTENTS RETAINED)
TYPICAL HYDROGRAPHS THROUGH TREATMENT
TIME (HOURS)
BOD REDUCTION
100%
80 %
68 %
59 %
48 %
0 %
BOD (LBS/MIN)
NO SWM CONTROLS-(2,575 LBS)
GREENBELT POND AND SURFACE RETENTION ON UNDEVELOPED INDUSTRIAL LANDS (INPUT TO TREATMENT)-(2380 LBS) (CONTROLS APPLY TO 30% OF DEVELOPABLE LAND)
SWIRL CONCENTRATOR ONLY - (1948 LBS)
STORAGE/SEDIMENTATION ONLY -(1,546 LBS) (STORAGE CONTENTS RETAINED)
SWIRL CONCENTRATOR AND STORAGE/ /SEDIMENTATION - (1,240 LBS) (STORAGE CONTENTS RETAINED)
TYPICAL BOD POLLUTOGRAPHS THROUGH TREATMENT
TIME (HOURS)
SUSPENDED SOLIDS REDUCTION
100%
81%
60 %
57 %
41 %
0 %
SUSPENDED SOLIDS (LBS/MIN.)
NO SWM CONTROLS - (41,566 LBS)
GREENBELT POND AND SURFACE RETENTION ON UNDEVELOPED INDUSTRIAL LANDS (INPUT TO TREATMENT) - (38,075 LBS) (CONTROLS APPLY TO 30% OF DEVELOPABLE LAND)
SWIRL CONCENTRATOR ONLY - (25,023 LBS)
STORAGE/SEDIMENTATION ONLY - (21,648 LBS) (STORAGE CONTENTS RETAINED)
SWIRL CONCENTRATOR AND STORAGE/SEDIMENTATION - (14,035 LBS) (STORAGE CONTENTS RETAINED)
TYPICAL S.S. POLLUTOGRAPHS THROUGH TREATMENT
TIME (HOURS)

FIGURE No. 1

number of consulting engineering firms are now familiar with these mathematical models and are increasing the utilization of them in new designs for urban drainage.

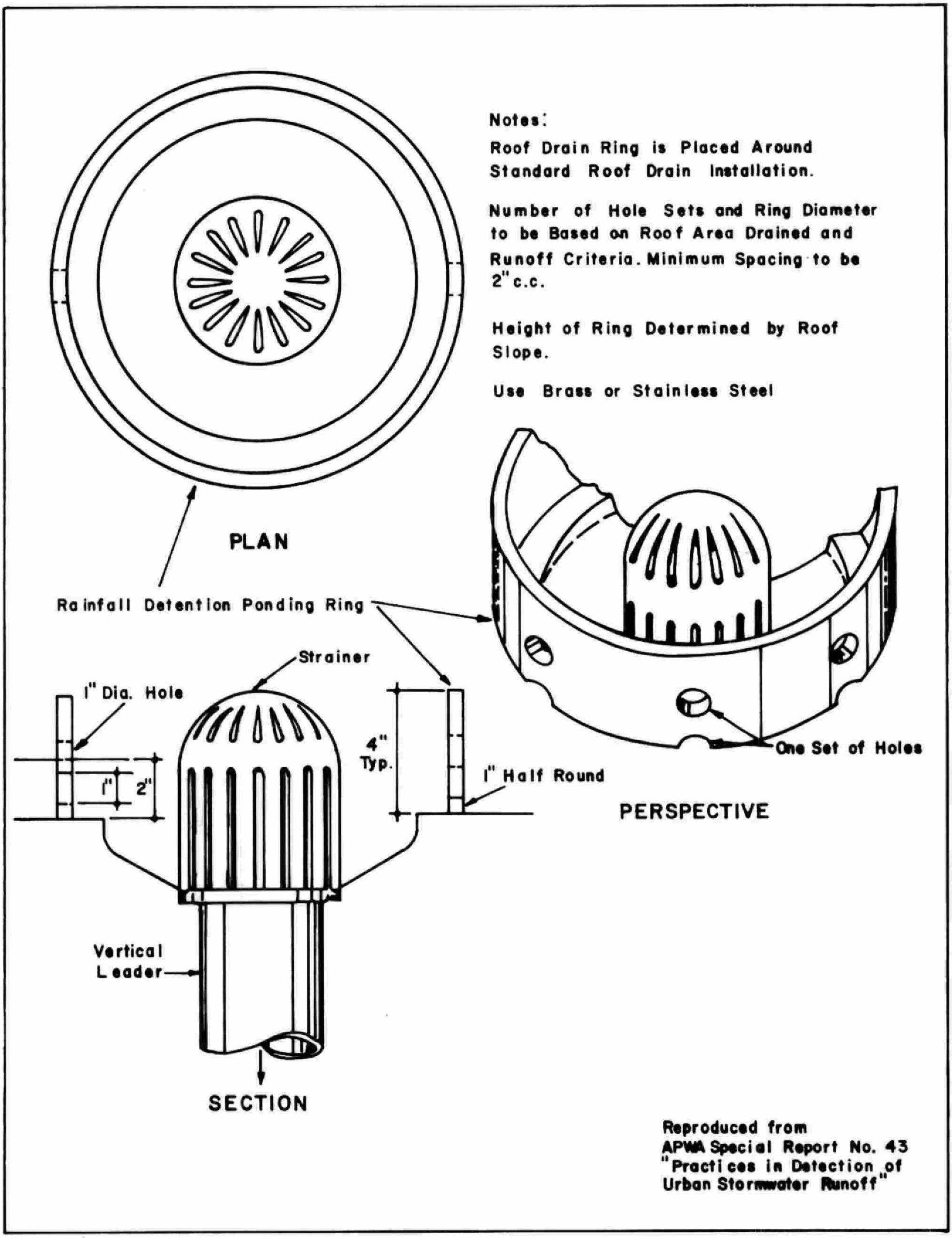
To give a few examples of typical applications, mathematical models have been or are being used for the planning and design of new developments such as the eastern community of the City of Ottawa and the south urban area in Nepean and Gloucester Townships adjacent to Ottawa. They are also being used in the design of the New Merivale Industrial Colony in an existing, partially developed, watershed area in Nepean Township and for the analysis of existing combined sewer areas in Cornwall and the Borough of East York in Metropolitan Toronto. The cities of Toronto and Vancouver have both engaged Dorsch Consultants to utilize their proprietary model in the analysis of each city's combined sewer system.

Storm water detention

One of the deficiencies of the Rational method is its lack of ability to compensate adequately for the effects of upstream storage in reducing peak runoff flows. The new mathematical simulation models are capable of taking into account these effects and a number of management techniques have been developed for creating this storage for evaluation by the model.

Such techniques include storage on streets and sidewalks, on rooftops and parking lots of industrial buildings, in parks and school-grounds, etc. which have been created by combinations of weirs and/or restricting orifices at inlets. Consideration must be given to the slopes of the storage surface and the depth of water permitted to accumulate.

The City of Winnipeg has developed storm water management techniques by the use of impoundments as a part of the planning for storm water storage and runoff. In many locations these impoundments are designed to provide additional benefits, as well, for recreational uses. In general, they have found the depth of storage should be limited to not more than four feet in residential areas but can be increased to six feet in industrial areas. In order to provide some degree of safety the retaining embankment should not have side slopes steeper than 7:1.



RAINFALL DETENTION PONDING RING FOR FLAT ROOFS

FIGURE No. 2

Another device which has been receiving some attention recently is the Hydro-Brake system which has been developed and is sold by the Hydro Storm Sewage Corporation of New York City. The Hydro-Brake is a form of orifice control designed to regulate a more or less constant rate of inflow of storm water into an existing sewer of limited capacity. This is achieved by providing a storage structure to which all storm water runoff is directed and which has the Hydro-Brake regulator on the outlet connection to the existing sewer. Some overall economies have been indicated by the use of this system.

Sanitary sewers

In general, sanitary sewer systems for municipalities are all designed on the basis of utilizing gravity sewers, most particularly if lift stations and force mains are considered an integral part of the gravity sewer system.

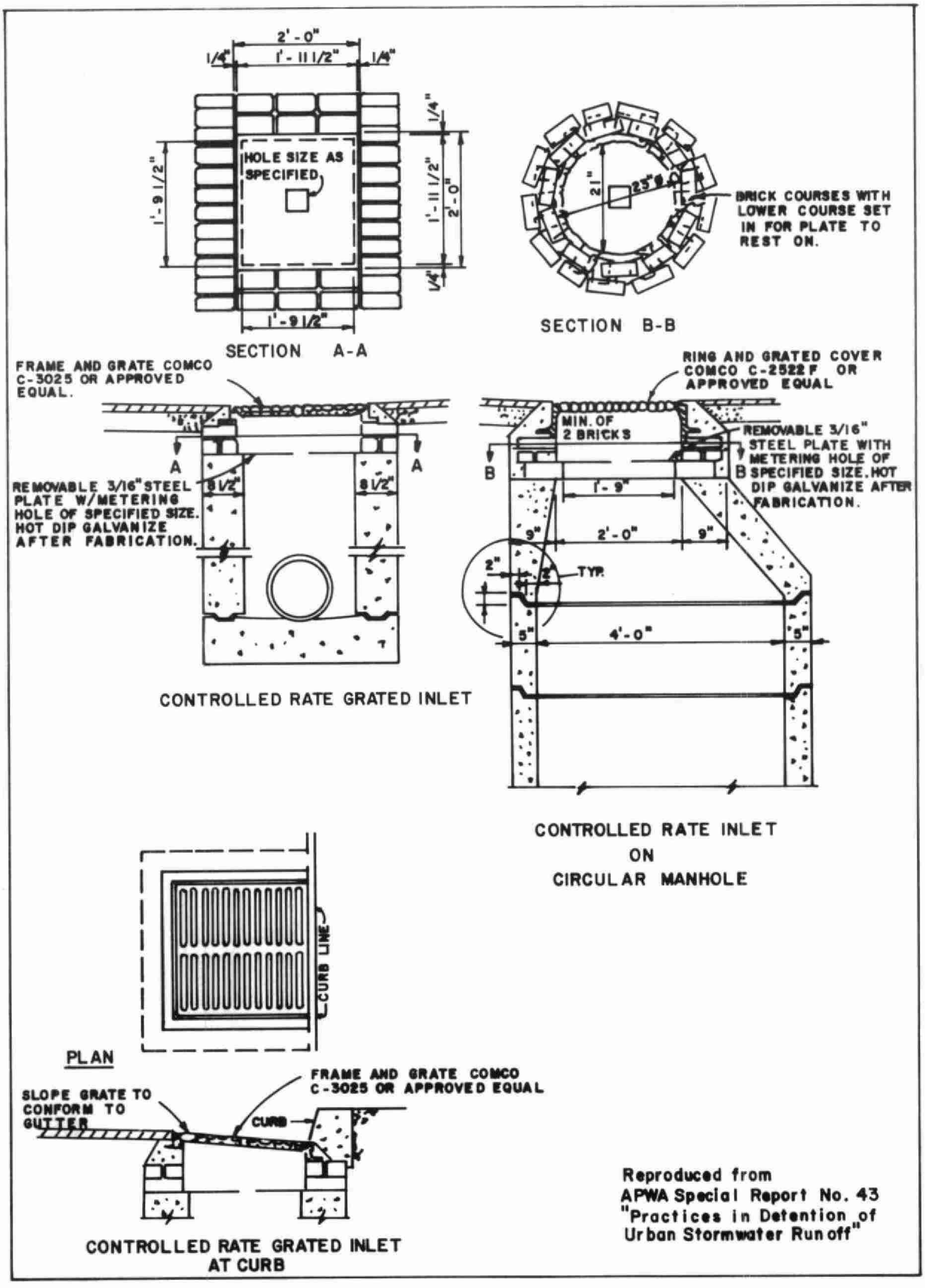
Pressurized sewer systems include a system of relatively small diameter pipes into which the wastes from each building are discharged by means of a sump pump. It would seem to have limited application for some subdivision developments which could not otherwise be serviced by gravity sewers. Such a system is reported to be servicing an area of 26 houses in West Vancouver.

Vacuum systems work on the opposite principle to the above in that houses are connected to a central station where a vacuum pump sucks the flow in the system to a storage container from which it is pumped for disposal either to a tile bed or to an adjacent municipal gravity sewer system. As for the pressurized system, the vacuum system would seem to have a limited application. Again, such a system is reported to be servicing a number of houseboats at False Creek in the Vancouver area.

Both pressurized systems and vacuum systems have received some consideration for application to the servicing of summer cottages in the resort areas of Ontario.

Partially separated sewers

Table 3 attempts to classify combined and partly combined sewers as compared with separate storm and sanitary sewers.



CONTROLLED RATE INLETS

FIGURE No. 3

TABLE 3. CLASSIFICATION OF COMBINED AND PARTLY COMBINED SEWERS AS COMPARED WITH SEPARATE STORM AND SANITARY SEWERS

Features	Combined Sewers	Partly Combined Sewers	Interconnected Storm & Sanitary	Separate Storm	Separate Sanitary
A. Flow Mixtures at Peak Flow Conditions	1 Part San. on 50-70 Parts of Storm Flow	1 Part San. on 10-50 Parts of Storm Flow	1 Part San. on 5-20 Parts of Storm Flow	Storm Flow with traces of San. Flow	San. Peak Flow 2 to 4 times D.W.F.
B. Flow Sources Identification	Servicing all Storm and Sanitary Drain Connections	Part of Storm Flow mainly from catch basins, collected in separate "street sewers" San. flow plus balance of storm flow in partly combined sewer	Adjacent separate sewers interconnected intentionally for relief or incidentally such as from major leakage and infiltration	Except the odd incorrect san. drain connection storm sewer laterals are connected only Catch basin connections	Sanitary flow dilution very limited to normal incidence of inflow and infiltration
C. Other Features	Combined trunk sewers may receive flow from upstream san. or storm sewers	Sometimes original storm sewer receiving sanitary or combined flow from upstream	Interconnection in system may include san. and/or storm sewers draining into combined sewers	Storm flow only draining to open water by gravity	Sanitary flow conveyed to sewage treatment nearly always by pumping
D. Typical Municipal Examples	City of Cornwall (most of the older cores in larger municipalities	City of Toronto	City of Brockville	Modern suburban development in most municipalities	

A combined sewer system can be defined as a system intentionally designed to carry both storm water runoff and sanitary wastewater. A partly combined sewer system is considered to be identical to a partially separated sewer system.

The City of Toronto has had a plan of construction for a number of years whereby a new system of storm relief sewers and local street sewers is constructed to take surface runoff. Roof water and foundation drainage continues to discharge to the original combined sewer along with the sanitary wastewater. As old buildings are torn down or renovated for redevelopment the internal plumbing system is required to be separated.

Due to an unusual situation of jurisdiction in the County of Halifax, Nova Scotia, a two-pipe system was installed by the County for local sewers. One pipe received the sanitary wastewater, the other pipe, called a "clearwater" sewer, received roof water, basement drains and foundation drains. Surface storm water runoff came under the jurisdiction of the Department of Highways and was either carried in ditches or shallow storm sewers.

A similar three-pipe system of sewers has been installed in new subdivisions at Brampton, Ontario.

In the Province of Quebec practically all foundation drains and most roof drains are connected to sanitary sewers and are the cause of major problems. Future policy is directed towards the design of partially separated sewers to eliminate these drain connections from the sanitary sewers.

COMBINED SEWER OVERFLOWS - POLLUTION AND ABATEMENT

Attitudes and Policies

In the survey of combined sewer problems in Ontario, the municipalities were asked to indicate the problems which were predominant in their sewer systems. Of the 69 municipalities which indicated combined sewer systems, the responses to suggested typical problems were as follows.

From the following it seems evident that municipal officials have more concern with respect to the quantitative problems than the qualitative problems. The concern of provincial regulatory bodies with the

Problems	Affirmative Replies
Infiltration and inflow	83%
Basement Flooding	72%
Overflows	71%
Interconnections	61%
Overloading	57%
By-passing	55%
Area Flooding	41%
Recreational Pollution	30%
Erosion	21%

qualitative problems of pollution and erosion caused by combined sewer overflows has not received the same emphasis at the municipal level. These attitudes of the different levels of government seem to be similar in the various provinces across Canada.

In the Maritimes, it was indicated that, although combined sewer overflow may be a major source of pollution, it was considered that in most instances it was not a significant source in relation to other sources of pollution. It particularly was not a significant source along the coastline except in the vicinity of shellfish beds. Since there are only a few cities on the Western Prairies where combined sewers exist, it was felt that the overflow from these sewers was not the major source of pollution in relation to other sources.

Quebec also felt these overflows were not a major source of pollution except where they may occur near water intakes. In British Columbia, the magnitude of the problem seemed to be related to the receiving water. It is assumed that this would probably refer to inland municipalities on rivers and to seacoast municipalities.

Most of the provinces do not have any fixed policy established with respect to the control of combined sewer overflows. Where unofficial standards are practiced, they are generally based on discharge quantities. British Columbia and Ontario, however, do relate controls to the receiving water quality and use. The province of Quebec has provided 100 percent subsidies for municipalities undertaking master drainage plan studies.

Overflow Controls

Sewer separation

The policy of constructing separate sewers for new installa - tions has been almost universally adopted across Canada except for a few instances which have been mentioned earlier.

The problem of separation of flows in municipalities having combined sewer areas has received considerable discussion. Until recently, it was considered that separation was practically the only technique available to effectively eliminate overflows from combined sewer systems. One technique, as utilized by the City of Toronto, involves the installation of trunk storm relief sewers and new local street sewers to divert a large portion of the storm water runoff from the combined sewers into a separate storm sewer system for discharge directly to Lake Ontario.

Sewer separation has been adopted as a general policy in the Provinces of Quebec, Saskatchewan and British Columbia and is also practically the only technique used in the Maritime provinces.

Although sewer separation is widely used in Ontario and Quebec, it is not considered to be the only technique for overflow control. Similarly, in Manitoba, separation is only one of several techniques.

Separation of sanitary wastes and storm water runoff was initially approached as an economical consideration with respect to treatment plant operation. It soon became apparent, however, that the enormous costs of complete separation of sewers were not equally compensated by economic considerations. Nevertheless, full separation of the flows was generally considered necessary for environmental protection but, where this was not considered to be economically feasible, some partial separation was used to relieve basement flooding in problem areas.

Inflow and infiltration

Inflow is generally described as that water which is discharged into sewer lines from rain water leaders, basement drains, foundation drains, commercial and industrial clean water discharges and any surface waters which are deliberately directed to the sewer. This is distinquished from infiltration which is considered to include groundwater which may be

entering the sewers and house connections through defective lateral connections, defective joints, broken and cracked pipes, leaking connections through manhole walls, etc.

As was indicated earlier, inflow and infiltration are the most widespread of the combined sewer problems in Ontario.

Inflow. The connection of roof rain water leaders to sewer systems is one of the most controversial problems of inflow to sewers. In past years, it has been a common practice in many municipalities to connect rain water leaders to foundation drains and then to the sewers in the street. Sometimes these street sewers were separate storm sewers and sometimes they were combined sewers. In many instances, where only a sanitary sewer was available in the street, these have been connected to this pipe. It is now generally conceded that rain water leaders should not be connected to sanitary sewers and many municipalities no longer require this to be done. Some places have even made it a requirement that rain water leaders be discharged onto the ground at a certain distance from the house or building.

New Brunswick, as in the other Maritime provinces, indicates that rain water leaders should discharge onto the ground for seepage into the soil. There are a few instances where they are permitted to be piped to street gutters or surface ditches and a City of Halifax by-law still requires rain water leaders to be connected to the street sewer although this by-law may not be as closely enforced as it once was. In most municipalities in Ontario, the requirements are for connection to storm sewers or, in some places for disconnection for discharge onto the ground. A similar practice seems to prevail in Saskatchewan and in British Columbia. Manitoba has indicated they prefer roof drainage to be discharged on the ground for seepage into the soil or to find its way to the street gutters.

In general, foundation drains are connected to the sewer in the street and it does not seem to matter too much, as far as municipal regulations are concerned, to which type of sewer the drains are connected. Each province seems to have its own preferences but there is no uniformity across the country.

It would seem that there is a general feeling that groundwater around houses and buildings should be drained away either by direct connection to a street sewer or by a sump pump in the basement floors in order to provide protection from damage to foundations and basement floors due to water pressure and uplift from the groundwater. Problems occur, however, when the street sewers are surcharged during times of peak flows or storm runoff. At these times, the surcharge in the sewer backs up the house connection and, if there is insufficient vertical distance between the sewer and the building foundation, the surcharge will percolate from the foundation drains into the ground around the basement walls. Where the roof drains are connected to the foundation drains, the situation is compounded.

In one area of the City of Ottawa, foundation drains are connected to three-part basement sumps. The foundation drain is connected to the central sump from which it can flow into another sump containing a backwater valve. During times of dry weather flow, the foundation drains flow through this second sump by gravity to the street sewer. When the street sewer is surcharged by high flows, the backwater valve or flap gate closes, the foundation drain flows into the other compartment which contains the sump pump. The sump pump is either connected to the drain to the sewer or discharged on the surface of the ground. Only a few houses in the subdivision have this type of facility and these are not always completely successful in operation.

In Manitoba there are locations where foundation drains are connected to the sanitary sewers and major flooding of basements has been experienced as a result. British Columbia has found that these discharges to sanitary sewers in the older developed areas are very difficult to rectify. Present Quebec policy is to discourage the practice of connecting roof and foundation drains to sanitary sewers.

Generally, the connection of roof and foundation drains is regulated by municipal sewer use by-laws.

There is a general indication of a trend towards controlling the surface runoff quantity by means of taking advantage of existing natural drainage through urban planning often using surface ponding through detention ponds or impoundment. At the present time, such urban

planning has mostly been done by progressive developers on a voluntary basis. The City of Winnipeg, however, has made a policy of impoundments for the storage of surface water runoff. Wherever possible such impoundments are developed into recreational and landscaped features.

Infiltration. A few municipalities in Canada try to effect some control of infiltration through municipal sewer use by-laws but even where this is not controlled by an official by-law there is generally a standard of practice with respect to control of infiltration. The requirements are generally directed through either the engineering design standards set up by the municipalities or the consulting engineers' specifications.

In an attempt to control the quality of sewer pipes, the provinces of Ontario and Quebec have set out prequalification requirements for quality control for pipe manufacturing companies.

Usually leakage tests are specified to be undertaken at the time of construction. There is some variation in the methods to be used in conducting these leakage tests. For example, a typical procedure in Ontario is for the sewers to be tested upon completion of their installation and backfilling either by an exfiltration test or an infiltration test depending on the level of the groundwater table. The amount of leakage allowed for in an infiltration test may be specified at 0.25 gallons per inch of diameter per 100 feet per hour or an equivalent in other units. This allowable leakage may be increased by 25 per cent for exfiltration tests plus an allowance of 0.2 gallons per hour per foot of head above the invert for each manhole included in the test section.

In the Maritimes, the general practice for leakage tests is by means of exfiltration tests made prior to backfilling. This is done to permit the contractor to rectify the leaks prior to completing the installation and backfilling.

One of the biggest problems with infiltration is often in the section of private drain between the street line and the house which is not included in the normal leakage test and where there is a minimum of inspection and control.

Where infiltration is observed in existing sewers, it can often be corrected by the use of TV inspection and the injection of chemical

grout into the leaking joints. The City of Toronto has developed a technique for inserting a new polyethylene liner into an existing sewer pipe where infiltration has been excessive.

Overflow regulators

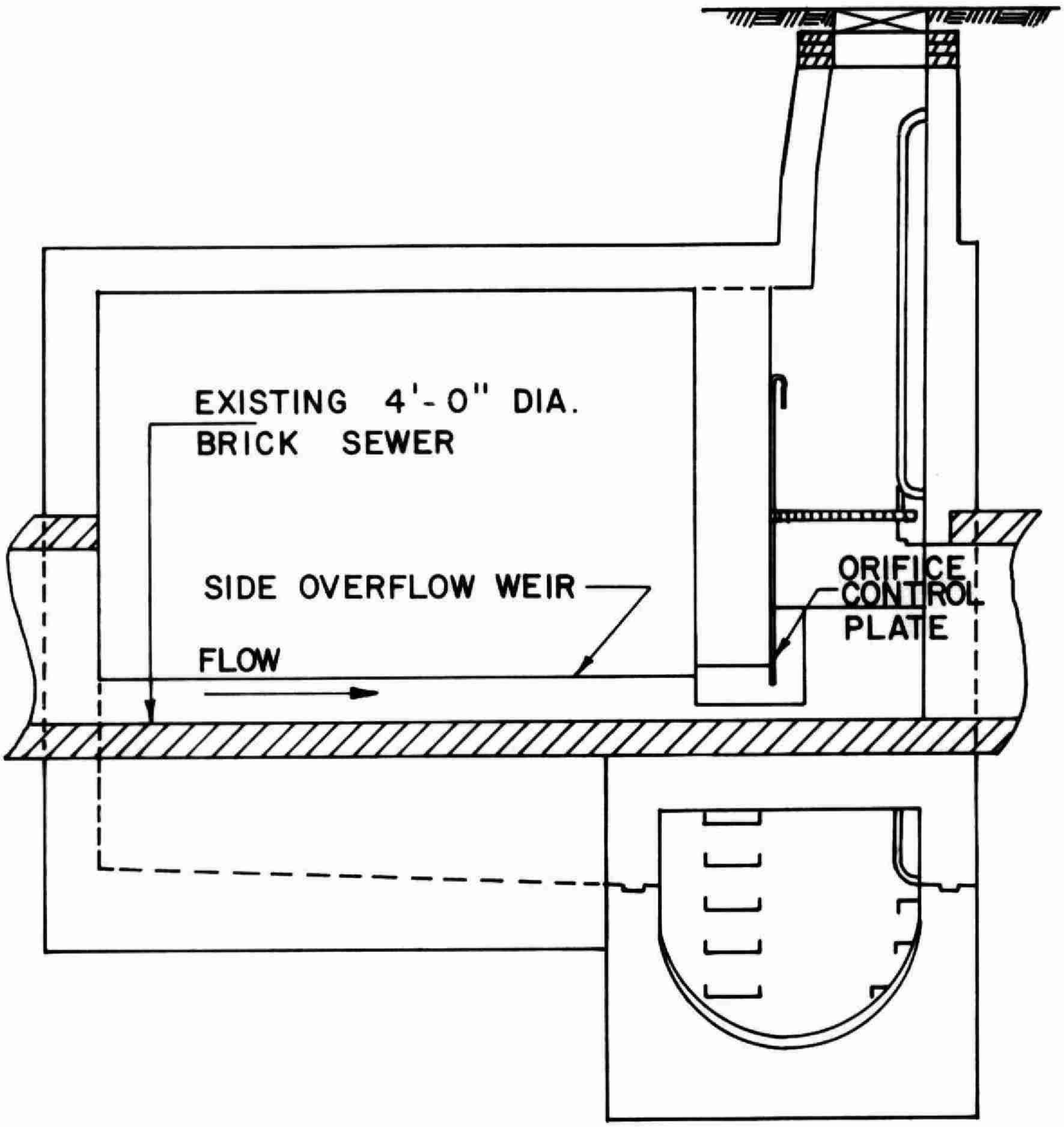
In certain areas where overflows from combined sewers cannot be avoided, it is necessary to provide some form of regulator to control flow to the treatment facility. Such regulators are generally set to permit overflows when the rate of flow exceeds three to four times dry weather flow (DWF) on the average, although the variation ranges from 2.75 to 8.0 DWF.

In some instances, a sewage pumping station may be considered as a form of regulator in that the discharge is limited by the rate of pumping. Side overflow weirs (Figure 4) are probably the most common form of regulator where required. In the City of Toronto these weirs are combined with a submerged underflow weir or orifice to control the amount of flow retained in the existing combined sewer according to its capacity.

The Municipality of Metropolitan Toronto has recently installed a new interceptor to receive flows from the City's combined sewers (Figure 5). The intercepting structures are designed to divert the combined sewer flow into a control structure which will regulate the discharge to the deep intercepting sewer. The inlet to the structure is controlled by calibrated sluice gates and the discharge flows out through a vortex chamber to drop in a regulated flow through a vertical downpipe. As the intensity of a storm moves across the Metropolitan area, the flows in the combined sewers will peak at different times. By controlling the sluice gates in the intercepting chambers to permit maximum diversion of combined sewer flows from each combined sewer as the peaks are reached, the maximum capacity of the intercepting sewer can be utilized. This system operation could also be considered as a form of quality control for the combined sewer system.

Innovative solutions

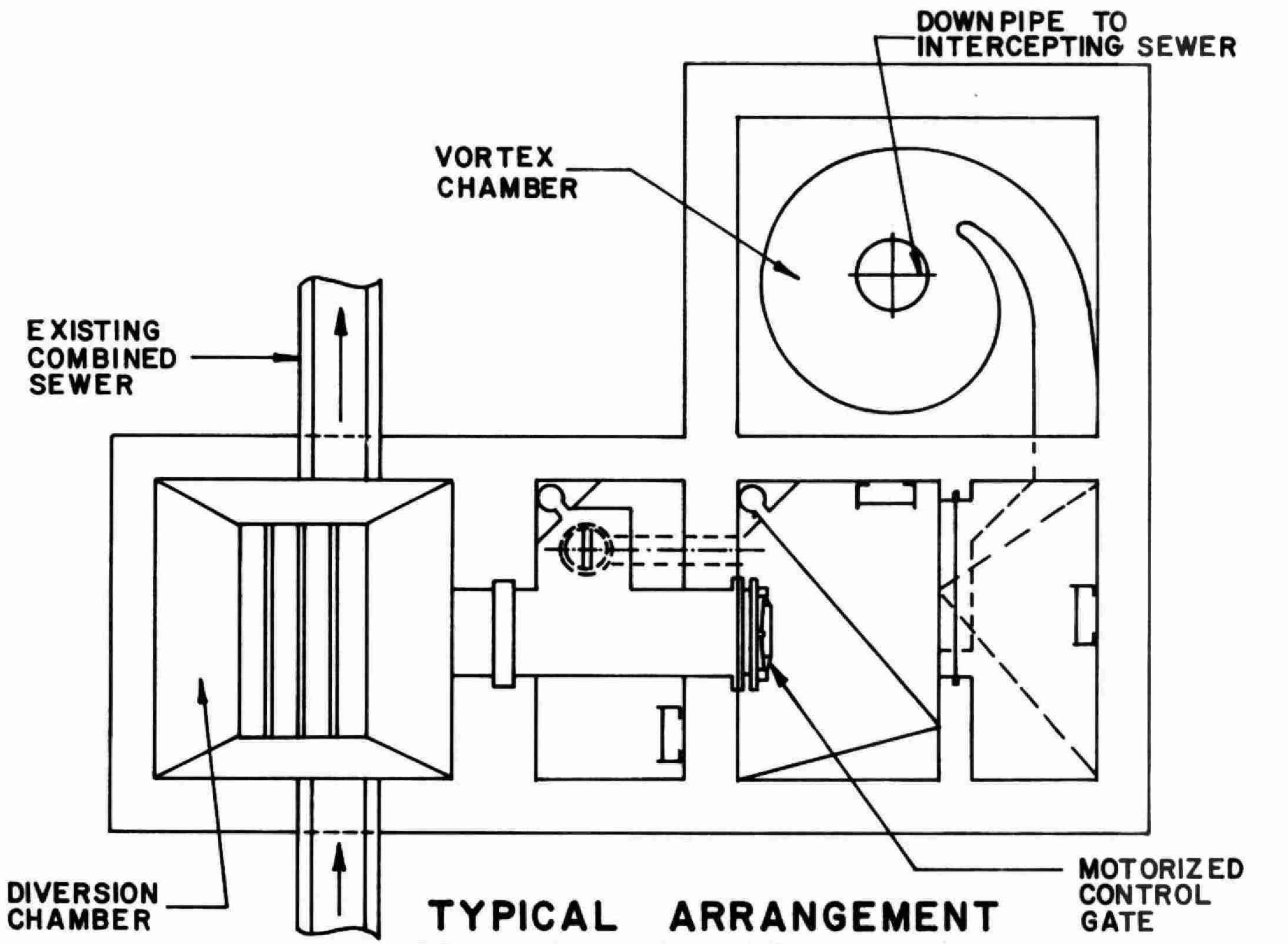
Computer control systems. The intercepting system installed for the Municipality of Metropolitan Toronto is being planned for the possibility



TYPICAL

SIDE OVERFLOW WEIR CONTROL

FIGURE No. 4



TYPICAL ARRANGEMENT OF VORTEX CHAMBER FOR METROPOLITAN TORONTO INTERCEPTING SEWER

FIGURE No. 5

of eventual computer control in order to maximize the interception of combined sewage flow to the capacity of the intercepting sewer.

With the exception of possibly a few of the larger cities in Canada, such as Halifax and Winnipeg where some interest has been shown, it does not seem that a computer control system is an economically feasible consideration.

Drag reducing additives. The possibility of injecting a chemical additive into sewers which have inadequate capacity to handle peak flows in order to reduce surface friction and increase the flow on a temporary basis has been demonstrated at an installation in Dallas, Texas. The feasibility of such an injection to improve hydraulic characteristics seemed to have been adequately proven by the system and the additives did not appear to be detrimental to waste treatment plants and receiving waters.

There is no apparent instance of such an installation in Canada.

Urban Watershed Management

Street cleaning practices

Street cleaning practices of one form or another are universally used across Canada. There are, however, some variations in the preferred procedures as some municipalities prefer dry sweepers or vacuum sweepers. Other municipalities include street flushing in conjunction with the street sweepers. The frequency of street cleaning is variable and in different municipalities it depends on the type of the area, the roads, weather conditions, availability of funds and the equipment used.

Although personnel at the managerial level generally recognizes the dependency of street runoff pollution on its cleaning practices, it seems that this is not likely to extend to the operational staff. Obviously, a better form of communication and dissemination of information on this matter is required.

Snow removal

The policies with respect to snow removal are generally recognized to be a municipal responsibility and consequently any policy

would vary considerably from one municipality to another. Similarly, the type of equipment used varies considerably. The most common type of equipment used is the installation of plow blades on the front of trucks in order to push the snow to one side. Other types are graders, blowers, loaders, trucks and snow melters. The frequency of snow removal is generally controlled by the quantity of snowfall but may also have budgetary constraints particularly toward the end of the winter season.

Snow dumps are often used to store the snow until such times as warm spring weather will cause it to melt. Where convenient, these snow dumps are often located along the sides of major water courses. In municipalities along the seacoast of the Maritime provinces, disposal of the snow is usually made by dumping into the harbour.

The Provinces of Quebec and Ontario have shown some concern to municipalities with particular respect to the effect of disposal of snow in water courses and other receiving waters or on waste treatment plant operation. Such concerns most generally prevail in the municipalities located on fresh water rivers and lakes and most particularly with respect to the Great Lakes-St. Lawrence River System. There is, of course, less concern in municipalities located on the seacoast of the Maritime provinces and British Columbia.

In order to provide automotive traction on city streets during winter snowfalls, most municipalities use a de-icing material such as salt and/or an abrasive material such as sand. This seems to be fairly general in all provinces. The environmental impact of these de-icing and abrasive materials has been given some consideration and some tests have been done in Ontario and in Saskatchewan.

The extent of the problems of lead and other heavy metals as snow contaminants is not widely known although it is realized that there is other general debris mixed with the snow removed from the streets which may be of greater concern than salt. Snow dumps in commercial and industrial areas in Quebec and in some other locations are located so that the melting snow is directed into the sewer system.

The use of sand abrasive generally occurs only in special circumstances although it is predominantly used in Quebec City. It provides better traction on icy streets in very cold weather where salt

may not be effective in melting the ice. However, the use of sand creates considerable maintenance problems because of its accumulation in gutters, catch basins, in the sewers and at the treatment plant.

Sewer cleaning

Some cleaning of combined sewers is carried out other than regular maintenance particularly if there appears to be some form of obstruction in sewer. Various forms of cleaning are utilized such as bucket operation pulled from one manhole to another, hydraulic spray and, in some instances, balls are floated down the sewer in conjunction with sewer flushing. Catch basins are usually cleaned by vacuum gulley cleaner trucks once or twice a year.

Storm Water Treatment

Attitudes

This is a subject which is being given more and more attention by regulatory bodies. Needless to say, it has not been received with a great deal of enthusiasm by municipal authorities who look at the considerable potential costs involved and have considerable reservations with respect to the benefits to be obtained for these costs. Nevertheless, the Province of Ontario has taken steps in this direction for flows into the Rideau River in the Ottawa area. Manitoba and Quebec are studying the matter and the Province of British Columbia has indicated this to be one of the provincial control objectives and has some studies in progress.

The main objective for treatment at the present time would seem to be the removal of suspended solids, reduction of biochemical oxygen demand and possible consideration of chlorination of the outflow. This aspect is being studied in Ontario through the Urban Drainage Subcommittee of the Canada-Ontario Agreement for Great Lakes Water Quality.

Types of treatment

Surface ponds, of course, provide a degree of storm water treatment although their prime function is peak flow attenuation.

Storm water tanks also provide storage for reduction of peak flows but their usefulness in quality control is their prime attribute.

Because they usually occur as downstream storage they are suitably located for storm water treatment prior to discharge to the receiving water.

Surface ponds and holding tanks

Surface ponds. Surface ponds are being utilized in Manitoba, principally in the City of Winnipeg, for storm water impoundment. Because of the relatively flat gradients of the land in the area, Winnipeg has found these impoundments to be very advantageous in the control of runoff quantity. Winnipeg's report on Storm Water Management by the Use of Impoundments outlined a number of factors for consideration for the use of impoundments. The report was approved and the concept of impoundments was adopted for use in the city.

There have been a small number of surface ponds used in Alberta essentially for much the same purposes as the impoundments used in Winnipeg. In both Alberta and Manitoba, however, it has been found that some quality control benefit is obtained from the detention ponds due to the settling effects for solids in the flow, particularly the sediment which may be caused by erosion and carried from newly developing areas.

Holding tanks. Storm water holding tanks have been used mostly on combined sewer flows. Their purpose is to be able to catch the first flush of solids washed down the combined sewer at the beginning of the storm.

Sometimes these tanks are designed for in-system flows whereby the storm water passes into the tank and flows out the other end after a pre-determined detention time. This time is usually set to provide for a certain proportion of the suspended material to settle to the bottom. Another type of holding tank is the off-system design whereby the first flush of storm water is diverted into the holding tank until the tank is filled and then the weaker quality of flows in the sewer by-pass the tank and continue down the sewer to the outlet. In both instances, when flows in the sewers have returned to normal, the contents of the tank are usually drained back to the sanitary sewer system.

The Hyde Avenue storm holding tank in the Borough of York, in Metropolitan Toronto, is an example of the in-line system tank (Figure 6). This tank was installed a few years ago in order to mitigate the

FLOW DIAGRAM

BOROUGH OF YORK – HYDE AVENUE SETTLING DETENTION TANK

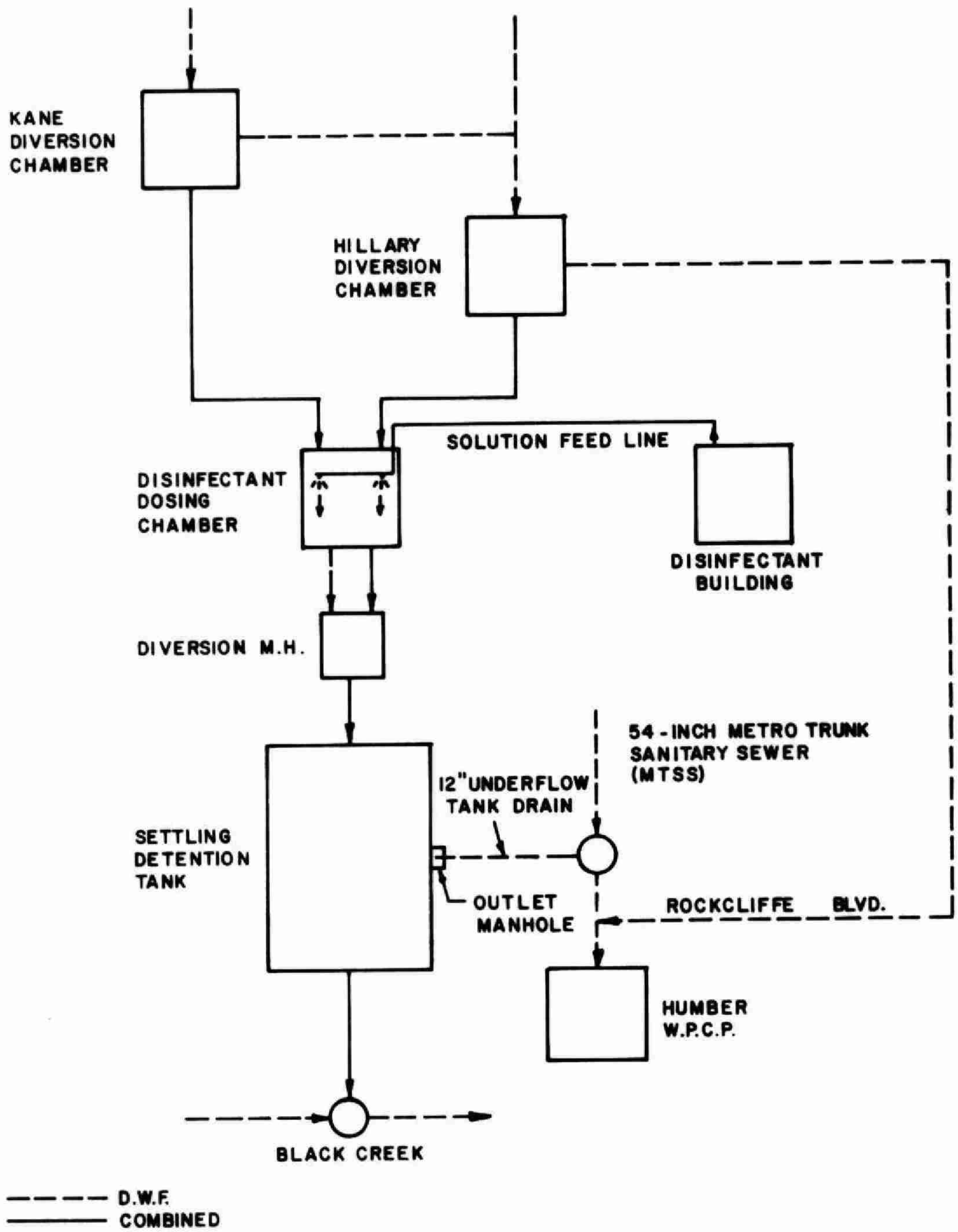


FIGURE No. 6

pollution of the Humber River and its tributary, Black Creek, caused by combined sewer discharges.

Quite a few years ago, the City of Toronto installed a storm water holding tank in High Park. This tank was a multi-compartment type of the off-system design. It was located to catch the storm water flows from a number of combined sewers meeting at the location. With the construction, by the Municipality of Metropolitan Toronto, of the new intercepting sewer from Ashbridges Bay to the High Park tanks, the existing combined sewers will be intercepted by the new construction and it is understood that the High Park tank will be taken out of service.

A few storm water holding tanks have been installed in Nova Scotia to resolve certain specific problems on the recommendation of the consulting engineers.

Operational problems

There are a number of problems that have to be considered in the design of surface impoundments such as depth of water and slopes of banks for safety reasons. In addition, there are some operational problems which require a certain amount of maintenance from time to time. It has been found that because of nutrients washed from ground surfaces, the development of algae in the ponds can become a problem if not controlled. Similarly, the development of mosquito and other insect larvae must be controlled. Surface ponds are also subject to settling of sediment transported with the storm water and after a period of time this must be removed in order to restore the capacity of the impoundment.

The contents of the storm water holding tanks, which remain after the flow of storm water into the tank has ceased, are usually drained or pumped into the sanitary sewer system. This practice takes up some capacity in the sanitary sewers but, if the discharge is properly timed and regulated, this should not create a problem. Whether the tank contents are discharged to the sanitary system or returned to the storm system will be somewhat dependent on the assimilative capacity of the receiving water and the degree of treatment required.

There are some feelings that the settled solids should not be returned to the sewer. There are advantages and disadvantages to be considered. By returning these solids to the sanitary sewer they will

be treated at the water pollution control plant but there is concern that some of these solids will settle in the sewer pipe during periods of low sanitary flow. There will be, however, a considerable increase in the maintenance and operational problems to remove this material from the tank and dispose of it in a suitable location. This could be a considerable factor if a number of holding facilities are required throughout a municipality and the contents of each tank are to be removed for disposal.

FIELD STUDIES

Purpose of Field Studies

Field studies will provide a background data basis that can be used to formulate projections for future requirements. This information may be required in order to adequately design new sewer systems based on current conditions. It may also be highly desirable to investigate any abnormal conditions which may be occurring in the sewer, such as excess infiltration or inflow, in order that they can be rectified.

Some of the new mathematical simulation models are quite sophisticated in the detail which is incorporated in the program. Since, in any computer program, the results which come out are only as reliable as the information which went in, it becomes quite necessary to collect actual field data for the input into the program in order that the model may be calibrated for the actual location and condition that it is being asked to analyze. Along the same lines, sufficient field data must be collected in order that the different hydrological parameters of the area can be determined and to provide a reasonable reference against which the results from computer simulation can be verified.

Measurements and Methods

The main concerns for field study measurements are those features that indicate runoff quantity and runoff quality. It is necessary, therefore, to observe the physical features of not only the sewers themselves but of surface parameters from the quantitative and qualitative aspect. This might include such things as ground slopes, depression areas, impervious areas, ground surface characteristics, drainage patterns, etc. It is desirable, also, to determine a coefficient

for calculating flow in the sewer pipe which can be used in analyzing conditions at varying flow quantities. Other quantities that need to be measured are the precipitation rate, variations in the flow rate indicated by rising or falling water levels and the quality of the runoff through sampling.

Wherever possible, it is desirable to have the precipitation quantities measured as near as possible to the centre of the drainage area contributory to the sewer being monitored. The number of precipitation measurement locations will depend, to some degree, on the size of the drainage area being observed and the accuracy required for the calibration of the model. In some locations, the precipitation records of the local weather office may be the only source of information.

One other aspect which is highly important once physical features are obtained is to be able to correlate the precipitation, flow and quality measurements. For this purpose, it is necessary that continuous recording instruments be utilized as much as possible for these measurements so that the timing of instantaneous variations can be coordinated amongst the various measurements. Centralized recording on a common chart recorder provides optimal time matching of all input parameters. Microprocessor or computer controlled data collection systems are gaining increasing acceptance for larger projects, especially where the volume of data to be collected and processed becomes prohibitive for manual analysis.

There are many types of instruments for measuring the various features. For measuring rainfall rates, the tipping bucket rain gauge is usually the most economic instrument, providing easy interfacing with recording instruments and telemetry systems.

For the measurement of the flow rate, a huge variety of different instruments is available on the market, many of them making extensive use of the latest techniques in digital electronics. Built-in processors convert measured depth and velocity signals into flow and control associated equipment such as samplers. The depth sensors used range from conventional floats, bubblers and "dippers" to ultra-sonic sensors and magnetic pickups. The applicability of each instrument for a given situation depends very much on the local circumstances. Of particular importance are the hydraulic conditions of the conduit in which the flow

is to be measured and the method of measurement whether by depth or by use of a measuring device such as a weir, flume or orifice.

One must be fully conscious of practical limitations to ideal conditions of measurement that do not adequately provide for backwater conditions or bottom sediment, etc. which may influence the results by several orders of magnitude. Surcharge conditions may require differential level measurements between adjacent manholes in order to obtain acceptable flow data.

There are a number of devices for sampling water quality. These generally consist of a small vacuum pump with a suction tube into the water flow at a suitable location. The liquid is usually drawn into a metering chamber from which it is released into a large common container or into a series of individual bottles. Sampling can be taken on a flow-proportional basis or sequentially, controlled by a preset timer. Most available samplers have some kind of a purging feature which cleans the sampling line between each sample. A few units provide also an event signal that allows the recording of the exact time a sample was taken. This is essential for short-interval sampling of storm runoff in order to properly correlate measured hydrographs and pollutographs. The synchronization of all events on a time scale is most important.

COMBINED SEWERS IN ONTARIO

Information from the study of combined sewers in Ontario has already been incorporated into previous sections of this paper. Information was collected from a large number of municipalities by means of responses to a questionnaire and by submission of reports which were undertaken by the municipalities or their consultants. An attempt was then made to assess this information to determine if there were any common denominators for correlation of combined sewer problems.

Unfortunately, the results of the analyses were inconclusive with respect to finding any significant common bond for combined sewer problems. A few interesting facts were observed, however.

Most of the municipalities in Ontario having combined sewers are older, well-established cities and towns located along the Great Lakes shores and along larger rivers or canal systems which provide a transpor-

tation link to the Lakes. It appears that the incidence of combined sewer systems on predominantly flat topography is slightly higher than on predominantly hilly topography. In a few municipalities where hilly topography was predominant, surface water runoff was not always a problem. This condition prevailed in the City of Brockville, for example, and the first significant sewer system in this municipality was constructed as a separate sanitary sewer system.

With respect to the historical development, it was noted that areas of municipalities which had combined sewer systems were almost entirely developed prior to the time when municipal waste treatment plants became considered. In the earliest days when sewers were constructed in Ontario, it was usually for the purpose of disposing of storm water runoff which ponded in the streets and yards and low areas. Later, when water disposal of household sanitary wastes came into practice, these were discharged to the drain in the street for transportation to the nearest water course, hence the development of combined sewers.

GENERAL SUMMARY

Concensus of Canadian Practices

It does not appear that there are any great discrepancies in the policies and practices used for urban drainage in the various provinces across Canada. There are minor variations in approach due to local conditions. At the present time, it appears that we are in the midst of a transition of new philosophies in urban drainage and storm water management and this has received more attention in some provinces than in others. This is probably partly due to geographical location and partly to economic growth considerations.

Nevertheless, provincial regulatory bodies are generally becoming more and more aware of the problems and concerned with the quality effects on receiving waters. Ontario has taken a definite step towards storm water treatment in requiring quality control of urban surface runoff into the Rideau River in the Ottawa area.

At the municipal level many of the larger and older cities and towns in Canada are concerned with both quality and quantity problems of urban drainage and most particularly where these problems arise from

combined sewer overflows. Many municipalities are looking into the newer methods and techniques for management of all aspects of urban drainage runoff including analysis by one or more of the mathematical simulation models that are now available for this purpose.

A number of research programs have been instituted through the cooperation of the Federal and Provincial Governments which have provided additional knowledge on the subject as it applies to Canadian conditions and have given considerable impetus to the application of storm water management techniques across Canada. The Canada-Ontario Agreement on Great Lakes Water Quality was established in 1971 in response to a recommendation of the International Joint Commission and has been a vital factor in this program.

The Canada-U.S. Agreement has enabled a close association with the United States Environmental Protection Agency. Considerable benefit has been obtained from the work done by that agency and the experience gained in providing a background for our own development work in this field.

Out of the new storm water management techniques there is increasing attention being given to methods of solving quantity and quality problems through the provision of upstream or downstream storage controls for combined sewer overflows and for inflow and infiltration. The importance of urban watershed management is becoming a vital factor in controlling pollution from street runoff and snow removal and disposal. The requirements and methods for possible storm water treatment are now being considered. It was not possible in the past to adequately correlate all of these factors into a unified approach to the subject but with the assistance of the computer and the advent of the mathematical models this is now becoming possible. There is still much work to be done, however, in collecting background data and refining and calibrating some of the technical aspects of the computer programs in order to obtain the closest relationships to actual conditions.

How Do We Stand?

The Canada-Ontario Agreement on Great Lakes Water Quality has published Research Report No. 45 which reviews "Practices, Policies and Technology of Storm and Combined Sewers in Foreign Countries". Reference

has been made to this report in assessing Canada's position in tackling urban drainage problems in relation to the progress made in other countries.

European countries

In most European countries the emphasis has been on controlling pollution from sanitary and industrial sewage. The demands of post-war reconstruction in Germany and France have, of necessity, taken priority of funds and, as consequence, the correction of the storm water pollution problem has only recently begun to receive attention. Many of the cities of Europe are serviced by combined sewer systems and although most new construction is for separate sewers, the increasing development and the high population densities have overloaded sewer systems causing combined sewer overflows.

Switzerland, Sweden, Germany and France are all giving more attention to the significance of storm water and overflow pollution and funds are being made available for extensive research projects. Obtaining adequate coordination of this research work has been, to some extent, a problem. In general, the efforts with respect to environmental clean-up have been instigated and administered by the federal governments. The application of these programs, however, has usually been the responsibility of lower levels of government.

In summary, it is probably adequate to say that each country has recognized the problem of environmental pollution. The control of sanitary and industrial pollution, however, has been given highest priority. The problems of storm water runoff and overflow pollution are presently receiving increased attention with consequent research and development towards practical applications.

United Kingdom

The United Kingdom, again, has placed emphasis on cleaning up sanitary and industrial pollution and considerable improvement has been achieved. Flooding problems of storm water seem to be regarded as more critical than the pollution problems.

Management of the water resources in the country has been entirely de-centralized and each area is responsible for its own water

management. There is an effort, however, to bring all research on storm water management under the direction of a single committee.

United States

The problem of environmental pollution in the United States has received considerable attention and a large correction program has been established with a target date of 1983. The necessary laws and funding have been provided by the Federal Government enabling it to work with State or Inter-state authorities in achieving the necessary goals.

Through the research that has been done and is being undertaken, the problem of storm water management is probably better understood in the United States than in any other country. Results have been achieved more slowly than was anticipated but the impetus has been developed and it is expected that it will be maintained.

Canada

As with the other countries, until recently the main emphasis of pollution control in Canada has been on sanitary and industrial wastes. Increasing attention is now being given to the problems of urban drainage. There is no indication that Canada is lagging far behind in its efforts in this direction.

In spite of this, there has not been a uniformity in the extent of the approach to the problem. Increased leadership, encouragement and, of course, funding assistance from senior levels of government are required before the ultimate goals can be achieved.

EROSION CONTROL METHODS DURING CONSTRUCTION

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INTRODUCTION

Magnitude and Extent of Erosion and Sedimentation

Erosion and sedimentation have played an important role in shaping the surface and subsurface features of the earth; the processes have occurred since time began. The exposure of mesas in the American midwest, as well as the rounding and smoothing of precambrian granites in the Laurentian Shield and the enormity of the Grand Canyon attest to the magnitude of the effects of natural erosion. Locally, the vast amounts of material deposited in the Interlobate moraine just to the north of Toronto and the layering of fine-grained sediments observable in the exposed faces of the Niagara Escarpment attest to the magnitude of the process of sedimentation extended over time.

Erosion and sedimentation are natural processes but the effects of such natural processes are seldom of great consequence where natural counteracting forces such as forests are operative. Of great consequence, however, is the erosion and sedimentation which occurs as a result of man's activities. Such erosion is characterized by high rates of soil movement over a short time frame. The magnitude of soil movement can be truly staggering when one considers that the estimated annual silt discharge of the Mississippi River at its mouth is 730 million tons [1].

According to a recent E.P.A. report [2], 50 percent of the sediment deposition is attributable to agricultural sources; but the highest rates of soil erosion are attributed to construction and active surface mining. Table 1, derived from [2] illustrates this point rather clearly.

TABLE 1. THE RELATIVE SOIL LOSS DUE TO EROSION FROM VARIOUS LAND USES

Land Use	Tons per mi^2 Per Year
Forest	24
Grassland	240
Cropland	4800
Harvested Forest	12000
Active Surface Mines	48000
Construction	48000

Values greater than those reported in Table 1 were reported by Wolman [3] for various construction projects in Maryland. Table 2 demonstrates some of these values.

TABLE 2. ANNUAL RATES OF SEDIMENT YIELD FROM CONSTRUCTION ACTIVITIES IN MARYLAND (from Wolman [3]).

Construction Activity	Tons per mi^2 Per Year
Industrial Park	72000
Construction Site	140000
Housing Subdivision	121000
Housing Subdivision	25000
Housing	5600
Housing (Probably a low estimate)	11300

Table 2 also shows that a wide variation can exist and that high rates of sediment yield do not accompany every construction project. The reason for this variability is due to the influences of the various factors affecting the rate of sediment yield such as slope gradient, slope length, soil erodibility, rainfall intensity and duration as well as the degree and type of soil erosion control practised. The influence of each of these factors will be described later in this paper.

Impacts Due to Erosion and Sedimentation

Impacts by erosion and sedimentation have been recognized for many years; the scientific literature abounds with such documentation.

The loss of soil which accompanies erosion causes the following:

- structure failure or damage,
- loss of valuable topsoil with consequent lowered production,
- tree mortality,
- change in direction of streams and rivers,
- destruction of aquatic habitats,
- fish mortality from high sediment concentrations.

Sedimentation, or the re-deposition of eroded soil materials can have the following effects:

- reduced fish populations through:
  - spawning bed degradation,
  - loss of fish habitat,
  - changes in aquatic invertebrate populations and species composition,
- sedimentation of water impoundments,
- changes in water quality affecting man's use of water, e.g. industrial and municipal uses,
- increased transport of deleterious persistent biocides and nutrients,
- decreased suitability for recreational uses such as swimming, viewing, boating and fishing.

Although fantastic amounts of material have been eroded and subsequently deposited over geological history, the rates of sediment yield have seldom been high. Consequently, the various floral and faunal components of natural ecosystems are generally intolerant of high sediment concentrations. The reason for such intolerance is associated with the relative stability in which most of the natural species have existed over the course of evolutionary time. Some species, however, are very tolerant of sediment concentrations and play a very important role in promoting soil stability especially where erosion and sedimentation processes are active such as river banks and beach dunes.

The Changing Attitudes of Society to Erosion and Sedimentation

Even with the effects of soil erosion and sedimentation presented, one may still be inclined to adopt a casual attitude, reasoning that the value of the project of construction expressed as a need of society exceeds the tangible and intangible values of the environment affected by erosion and sedimentation. This is especially true if one does not appreciate the fragility of the links with which each of the components of an ecosystem are connected, or that man's future well-being depends on the integrity of such ecosystems. Accelerated erosion and the consequent accelerated sedimentation can disrupt such ecosystems.

Over the course of time since the settlement of this continent, the trend has been towards an increasing intensity of land use. This

trend is not only caused by population growth which necessitates that land be used for basic necessities such as food and shelter, but also that technology itself consumes land through such things as the construction of industrial parks, and freeways. At the same time, a greater affluence has permitted greater mobility so that lands once too far distant for such activities as cottaging and recreational uses are now under increasing pressure for use by urban dwellers. At the same time, this same affluence and leisure time allowed more people than ever before to reflect on the course that society has been taking in its attainment of an ever higher standard of living based on material goods. It has been precisely the same affluence that society sought during the late forties and the fifties which allowed society to count the cost in terms of natural envionmental degradation during the sixties. The late sixties and early seventies saw the formation of associates, lobbies, and clubs all with the common goal of stopping or retarding the trend that promised a reduction in the quality of life. The year 1969, not only saw the passage of the National Environmental Policy Act in the United States, but saw the formation of a chapter of the Sierra Club in Ontario and a peak in the activities of Pollution Probe at the University of Toronto. A number of books were published in the same period [4, 5, 6, 7, 8] to mention only a few. In 1973, the first steps were taken publically in Ontario towards the enactment of the present Environmental Assessment Act through the issuance of a Green Paper on Environmental Assessment. In 1971, pressure on the Ontario Ministry of Transportation and Communications had reached a sufficient level of controversy that a special section, concerned with the integration of environmental factors into all Ministry decisions was created. Shortly thereafter, Ontario Hydro also created an environmental section because of the pressures being exerted which also resulted in the creation of the Solandt Commission.

It is also noteworthy that the Canada-United States Agreement on the Great Lakes was signed in 1972 which considerably increased the prestige and the power of the International Joint Commission for whom the Manual on Urban Drainage is being prepared.

Erosion and Sedimentation Control and Tomorrow

For those of you in the construction industry who will but take a few moments to reflect on the events of the past quarter century and extrapolate that knowledge to the future, it will at once be obvious that the maintenance of environmental quality will increasingly take on a more significant importance. At the same time, for those of you who do not care or dare to look upon what may appear to be either such a ridiculous mundane or impractical subject, you have my pity; I believe that your survival may be at stake or, at the very least, very seriously jeopardized. It is my firm belief that erosion and sedimentation control is no longer an academic and impractical subject, the effect of which can be considered as a trade-off to the attainment of society's material goods, but is becoming as necessary as the proper design of subdivisions, or the construction of sound and substantial buildings. An affluent society such as ours can not only afford, but is demanding an environment which proper and effective erosion control can at least assist in maintaining.

Erosion and Sedimentation - Some Basics

Erosion

Erosion is the detachment and transport of soil particles through the action of water, wind, ice or gravity. In terms of water-caused erosion, which will be the main consideration of this paper, erosion can take four forms:

- sheet erosion,
- rill erosion,
- gully erosion,
- stream and channel erosion and transport.

Sheet erosion is the detachment of soil particles uniformly over an area so that the loss of soil may be almost imperceptible. Generally, sheet erosion occurs on very gradual slopes where water velocities are low. On steeper slopes, sheet erosion rapidly takes the form of rill erosion in which small rivulets are formed by the concentration of water flowing down the slope. Where soils are especially erodible

on moderate slopes, such rill erosion can rapidly create gullies, especially on the lower sections of such slopes. Whereas sheet erosion removes soil uniformly by low volume and velocity flows, rill erosion removes soil from channels through the action of low-volume concentrated flows of moderate velocity. Gully erosion is created by high volume concentrated flows of high velocity.

The erosion that takes place in streams and channels is caused by high volume and velocity concentrated flows. The scouring of stream banks and the consequent formation of pools and riffles takes place as the stream responds to the tendency to follow the mathematical expression for a "sine-generated curve" because this is the type of curve involving the least work in turning [9].

The Universal Soil Loss Equation

The amount of soil erosion that might occur from sheet or rill erosion can be calculated by the use of the Universal Soil Loss Equation (U.S.L.E.) developed by Weischmeir [10]. This mathematical relationship accounts for all the factors affecting erosion. Originally developed for agricultural use, the U.S.L.E. has recently been modified by Clyde et al [11] for use by highway agencies.

The U.S.L.E. is: $A = RxKxLxSxCxP$, in which

A - is the computed soil loss per unit area, generally expressed as tons/acre/year.

R - the rainfall factor, is the number of erosion-index units in a normal year's rain. The erosion index is a measure of the erosive force of a specific rainfall.

K - the soil erodibility factor, is the erosion rate per unit of erosion index for a specific soil in cultivated fallow on a 9% slope, 72.9' long.

L - the slope length factor, is the ratio of soil loss from the field slope length to that from a 72.9' length on the same soil type and gradient.

S - the slope-gradient factor, is the ratio of soil loss from the field gradient to that from a 9% slope.

C - the cropping management factor, is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the factor K is evaluated.

P - the erosion control practice factor, is the ratio of soil loss with contouring, strip cropping or terracing to that with straight row farming, up and down slope.

For non-agricultural applications, the factors C and P can be dropped and substituted by the factor VM, the erosion control factor. The VM factor is applied to the Universal Soil Loss Equation as a single unit and accounts for all erosion control measures that may be applied on any given site. These measures include the use of vegetation, mechanical manipulation of the soil surface, chemical treatments, etc. [11]. The factor VM is, therefore, a measure of the effectiveness of various treatments in reducing the potential soil erosion under conditions of no treatment. Indeed, the factor CP has been used by Thronson [12] in the same way the VM factor has been used by Clyde [11]. With the use of the VM factor, the value of the U.S.L.E. is considerably increased since Vm values can be substituted in the U.S.L.E. to indicate an estimate of the amount of soil movement for a given treatment or approach (i.e. an alternative).

It may be noted that the factors K and R are governed by nature and cannot be changed in practice by man. The factors L, S and VM can, however, be varied by the earth-changer. Since slope length L is very closely related to the slope gradient S, it would be advantageous to consider these two factors as one factor but governed by the conditions described in the definitions presented above. Thus, by employing various combinations of slope gradient, length of slopes and treatments, considering these combinations as alternatives and evaluating them against the objectives, it should be possible to select that alternative which best meets all the objectives, i.e. the optimal alternatives. Among the objectives mentioned above may be those associated with minimization of the amount of soil erosion, the loss of trees at the top of cuts, costs, etc. After such an evaluation, the trade-offs associated with each alternative can be identified and a rational decision made on that alternative which best achieves all or most of the identified objectives. It should be noted that the process described meets the intent of the Environmental Assessment Act.

In order to use the U.S.L.E., its limitations have to be recognized. One of these limitations has already been mentioned: its inapplicability to erosion occurring in gullies or channels. Other mathematical approaches have to be employed to deal with these types of erosion.

Thronson [12] describes a number of limitations of the U.S.L.E. and also presents a number of principal reasons for the use of the U.S.L.E. One of the main points made by Thronson and recognized among experts in its use [13] is that it is most valuable when interpreted by qualified experts.

Sedimentation

When particles have been dislodged by the forces of erosion and transported by the water medium, settlement can only occur when the forces acting on the particle become less than the force of gravity. Sediment can, therefore, be transported for long distances by high flows especially if the size of particle is small. Since the specific gravity of transported mineral soil particles is generally greater than that of water, the particle will eventually settle out as the water velocity decreases. However, in the case of small particle sizes (e.g. colloidal clays) particles may remain in suspension for a long time after the water velocity has been reduced to imperceptible levels, as in a sediment trap. The resulting turbidity is an indication that greater upward forces are acting on the individual particles than the force of gravity acting downward.

Principles of Erosion and Sedimentation Control

From the previous discussion, three principles of erosion and sedimentation control can be identified.

Minimize soil exposure

Soil exposed to rainfall or running water will be detached and transported because of the transfer of energy from the erosive force to the soil particles. This process will continue at a rate dependent on the interplay of the factors identified in the discussion of the U.S.L.E. Under given conditions of soil erodibility, rainfall, slope gradient and

length, the removal of vegetation to expose soil will increase the value of the VM factor. Thus the most obvious way to minimize the amount of soil erosion is to maintain the VM factor at as low a value as possible. Often the only way to accomplish this objective is to minimize the area of exposure to that minimum amount needed for site development. However, the minimization of the area exposed may not be sufficient if the area exposed is situated on the most erodible site. Thus the retention of vegetation on sites which have the greater erosion potential will minimize the amount of erosion.

In those situations where it has been determined that erosion potential is high so that it is impossible to further minimize the amount of erosion by the selection of the minimum area for site development, consideration should be given to the minimization of the time interval and time period of soil exposure. For example, where the installation of services has been accomplished and the serviced lots are awaiting purchase and/or erection of buildings, the application of soil erosion control techniques on a temporary basis will again reduce the VM factor so that the erosion potential will not be realized. The various techniques that could be used include the application of seed and mulch, mulch alone, chemical soil stabilizers or mechanical means such as plastic sheets. It should be pointed out that the selection of the measure to be used will depend on such factors as costs, effectiveness, time of protection and weather conditions.

It is also well known that the time of the year during which soil is exposed will influence the amount of erosion that will occur.

Make water walk, not run

The erosive force of running water is well known; as water is allowed to concentrate, its velocity increases and the erosive force of such running water consequently increases considerably. Thus, whenever the velocity of running water is reduced, the erosive force of such running water is also reduced. Likewise, with a reduction in velocity, soil particles will settle out.

Many of the soil erosion control measures utilize this principle. The application of sod or seed and mulch will retard the concentration of water by acting as an energy attenuator to force water to walk rather

than run. The use of rip-rap in ditches accomplishes the same objective. It should be noted that the various techniques for slowing down the velocity of water have to be used in those situations where they will be able to counter the forces of such running water. Thus the use of sod in a steep ditch will only result in the loss or damage to the sod without reducing the amount of erosion.

Retain sediment on the site

Even with the application of the previous two principles, it can be expected that some sediment will be produced. The retention of such sediment on the site will greatly reduce the potential damage to environmental features. Sediment can be retained by two methods: filtering runoff as it flows and detaining sediment laden runoff for a period of time so that the soil particles settle out. This may be accomplished by the construction of sediment traps at strategic locations in drainageways or by the construction of sediment basins through which water is diverted. Frequently, the approach that is used to prevent environmental damage is to construct sediment basins or traps in order to directly attack what is perceived to be the main cause of the potential environmental damage - the sediment. Rather, the use of sediment retention methods should be considered as a back-up protective measure to the application of erosion control methods employed further up the drainageway. The best way to control sediment is to control erosion.

Planning for Erosion and Sedimentation Control

Much can be accomplished by planning for erosion and sedimentation control; not only can environmental damage from erosion and sedimentation be minimized, but the various alternative courses of action can be examined in terms of the attainment of other objectives such as costs, staging efficiency, or the minimization of damage to other environmental features.

In erosion and sedimentation control, good planning and good application will not only help to avoid erosion and sedimentation problems, but can also assist in identifying what should go where to mitigate the inevitable residual erosion and sedimentation problem resulting in spite of a planned approach. It is applicable not only in the "pure" planning

exercises, but even down to the "guy-on-the-job-in-the-field". For an effective program in erosion and sedimentation control, a good planning approach throughout the life of a project is indispensible. However, it should be noted that the success of the planning activities is ultimately dependent on the field personnel actually doing the work at either the construction or maintenance levels. Such is the scope of an erosion and sedimentation program.

Five levels of planning which take place relative to erosion and sedimentation can be identified. These are:

(a) provincial planning
(b) local and regional (official plan stage),
(c) subdivision approval (site planning),
(d) construction,
(e) post development.

Throughout this planning hierarchy, erosion and sedimentation control must take the forms of (a) avoidance or (b) mitigation. In the case of the higher level planning efforts, such as at the provincial level or at the regional and local levels, the main emphasis will be on the avoidance of erosion prone areas depending, of course, on the influence of the other factors at each of the respective planning levels. Often, in order to implement the plan resulting from the planning process at a given level, it will not be possible to avoid potential erosion and sedimentation problems, which then have to be dealt with at a subsequent planning level.

Erosion and sedimentation considerations may take on considerable importance at the level of subdivision approval. Erosion and sedimentation may take on a special significance especially where the impacts of erosion and/or sedimentation may be particularly damaging to local environmental interests, e.g. presence of a cold water brook trout stream or a particularly unique ecosystem.

There are four steps in planning for erosion and sedimentation control at the site planning level. The first is the inventory stage during which an investigation and analysis of the natural characteristic of the site such as soil types, slopes, rainfall, existing vegetation,

topography, etc. that will help the earth-changer anticipate where erosion and/or sedimentation problems may occur. During the second stage utilizing such information, the earth-changer can develop various alternatives (scenarios) which may incorporate various erosion and sedimentation measures in order to ascertain the constraints and opportunities which each alternative will present in terms of costs, utilities, lot layouts and effects on environmental amenities of the site. During the development of alternatives stage, particular care should be paid to the three principles of erosion and sedimentation control presented earlier.

The third stage consists of the evaluation of the alternatives against the various objectives identified in the study to this stage.

When all alternatives have been evaluated, that alternative which best meets all the objectives of the study can be selected for more detailed examination relative to obtaining approval of the appropriate authorities. At this stage, it may be found that none of the alternatives will be adequate in order to obtain the necessary approvals. In this case, further consideration of the details of the alternatives may have to be developed in a refinement process. The end result of this stage should be completion of not only a site plan, but also a detailed erosion and sedimentation control plan which will specify the types of controls to be used, the conditions under which such controls would be applied, the grading plan, location of haul roads, etc.

In terms of erosion and sedimentation control, the construction stage is as important in preventing impacts as the site planning level, since the day-to-day decisions of each individual on the site may be crucial in the identification of potential erosion or sedimentation problem areas which inevitably arise during the development phase. Such actions as the placement of excavated soil in a location where it might easily erode into an adjacent stream have to be evaluated against other alternative action courses by the man-on-the-job. The objective, in all cases, should be to minimize the amount of eroded material gaining access to a watercourse.

In order to communicate the concerns about erosion and sedimentation to those working on the job, it may be necessary to provide sensitivity training courses to workmen and supervisors. The development of memory-joggers, individual projection kits (similar to Audioscan) and

problem-action kits will supplement such courses. Not only must everyone on the worksite be responsible for a quality job in terms of erosion and sedimentation control, he must also perceive himself to be important. Thus incentives towards the attainment of erosion and sedimentation control objectives should be built into the program.

EROSION AND SEDIMENTATION CONTROL PROBLEM AREAS

During the site planning and construction stages, particular attention should be given to the seven erosion and sedimentation control problem areas identified by [14]. These areas are:

- slopes,
- streams and waterways,
- surface drainageways,
- enclosed drainage inlet and outfall control,
- large flat surface areas,
- borrow areas,
- adjacent properties.

Slopes

Runoff velocity increases as the slope gradient and slope length increases. Particular attention should be paid to the erosion potential under the following conditions:

(a) slopes are steep,
(b) slopes are without vegetation,
(c) soil erodibility is high.

Combinations of the above three conditions often occur; in which case, the erosion potential will be particularly high.

Streams and Waterways

There are several characteristics that serve to identify streams and waterways that are particularly vulnerable to erosion. Streams which have a small channel capacity with steep banks which will create high velocities at times of storm runoff are very susceptible to erosion. Streams which flow through areas of very erodible soil (common in bottomlands along stream courses) and streams having sharp meanders or

bends in the channel alignment are also prone to erosion. In general, wherever exposed erodible soil along a stream bank is found, especially in conjunction with a restricted channel, or sharp turns, corrective measures will have to be taken, especially if the resulting development will itself result in an increase in peak flows.

Surface Drainageways

Whenever water is collected in a drainageway before discharge to an outlet, its potential to erode is increased, especially under the conditions experienced at construction sites. It is here that the second principle mentioned previously is especially applicable: make the water walk rather than run. Often, because of the problems caused by the retardation of flows, this will only be practical in cases of low flows. The stabilization of drainageways will, therefore, have to be conducted.

Enclosed Drainage: Inlet and Outfall Control

Because of the increase in peak flows that often occurs as a result of the reduction in the retention of water on the site, stabilized drainageways may be inadequate to handle the flows without erosion. In such a case, enclosed storm sewers can safely convey runoff of high concentrations and velocities.

The installation of storm sewers before major building construction begins can aid in controlling site runoff and in avoiding erosion hazards. Where storm sewers are installed early in the site development, the inlets can be so modified to form sediment traps which will cause the settlement of larger-sized particles which otherwise would become trapped in the catch basins or transported to the outlet. A number of designs are available which involve either the excavation of the sediment trap with the inlet serving as the riser pipe or the use of various filter media to increase the depth of water in the drainage channel. In all cases, prompt attention must be paid to the excavation of accumulated sediments if the structures are to function adequately.

Large Flat Surface Areas

All areas of exposed soil are vulnerable to erosion. Clearing, grading and vegetative restabilization in these cases can be timed so

that the extent of exposed area and the duration of exposure can be minimized. Temporary seeding or mulching is required where large areas will not be permanently stabilized within recommended time limits.

Borrow and Stockpile Areas

Borrow and stockpile areas, because they consist of exposed soil, need to be considered as significant sources of soil erosion, especially in those cases where significant environmental impacts may occur. Under such cases, the three principles mentioned previously should be employed. In the case of stockpile areas, the location should be well thought out in order that such piles are not located so as to contribute sediment to potential impact areas. However, there is seldom any valid reason for leaving a stockpile area unvegetated; the cost of temporary seeding is insignificant.

Adjacent Properties

The protection of adjacent properties from accelerated erosion and sedimentation is an important concern. The earth-changer has a moral responsibility, if indeed not a legal responsibility to ensure that his work is of sufficient high quality so as to not create erosion and sedimentation problems on adjacent properties. The retention of sediment within the boundaries of the developing area and the design of the drainage system so that peak flows are accommodated by the drainage-way on the adjacent property must be given the same consideration as is given to deal with similar situations within the developing area.

EROSION AND SEDIMENTATION CONTROL PRACTICES

Appendix I provides a list of most of the known erosion and sedimentation control practices along with an indication of relative costs and effectiveness. Although prepared from literature on erosion and sedimentation control practices on highway rights-of-way, many of the same practices are applicable to developing urban areas.

Erosion and sedimentation control practices generally fall into one or a combination of categories:

(1) vegetative,

(2) structural,

(3) chemical,
(4) management.

Vegetative Erosion and Sedimentation Control Practices

The use of vegetation of various types according to the soil type, climate, time of year, aspect, etc. is one of the better known methods for controlling erosion. The practices always involve the application of vegetative fibres. Many of these practices, however, have some value in promoting sedimentation, generally in a diffuse, rather than concentrated manner.

Vegetative practices can be further broken down into:

(a) vegetative transplants,
(b) seeding,
(c) mulching.

Vegetative transplants

The use of vegetative transplants consists of the transfer of living vegetative material from a growing site to an area to be stabilized. Sodding is a common example, although the transplanting of trees and shrubs also falls into this category.

In general, vegetative transplants have the main advantage of providing an "instant" cover although sometimes special care is needed before the new roots gain an anchorage into the soil of the new site. In general, the practice costs considerably more than other practices involving the stabilization of large areas.

Seeding

The application of seed to a prepared seedbed is also a very common and relatively inexpensive erosion control practice. The application of seed is usually accompanied by the application of a mulch and/or a nurse crop in order to not only provide for erosion protection during germination and growth, but to also modify the microclimate of the seeds so that the maximum germination possible is practically ensured. However, because of the length of time required for the young seedlings to anchor the soil particles, erosion, in the form of rills and gullies, may cause damage to the slope. In addition, this practice is practically

useless by itself for late seeding before winter, since a temperature of approximately $42^{\circ}F$ is generally required for germination. The chief advantages of the practice are the low cost and the large area that can be treated in a short period of time.

Mulching

The use of mulch is similarly widespread since it too is inexpensive and will treat a large area in a short period of time. Traditionally, mulching materials consisted of straw or hay. In recent times, however, a variety of materials have been put on the market. One product consists of finely ground wood fibres with a tack and a green colouring. Another product utilizes a mixture of shredded newspapers, woodchips and waste raw cotton.

A variety of tacks can also be used with mulch in order to provide a degree of stability against the effects of wind and water. One of the commonest tacks is asphalt. A rather innovative mechanical means of integrating the mulch to the soil has recently been tried by the Ministry of Transportation and Communications. This practice consists of a heavy application of straw mulch (up to 2 inches) following the application of a seed mixture. The seed and straw are then integrated into the soil by running a heavy bulldozer having deep cleats perpendicular to the slope so that the straw and seed is "punched" into the soil by the cleats which are parallel to the slope. The straw not only provides a favourable microclimate for seed germination, but is anchored to the soil while the cleats ensure the contact of seed with the mineral soil and, at the same time, trap moisture and sediment act as mini-sedimentation traps.

Very seldom is mulching utilized without an application of seed because the extra cost of the seed is relatively insignificant and, the mulch serves a major protective function for the germinating seed.

Structural (Mechanical) Erosion and Sedimentation Control Practices

This group includes by far the greatest number of erosion and sedimentation control practices. In general, they can be grouped into six categories according to function as follows:

(a) retention,

(d) diversion,

(c) energy attenuation,

(d) surface modification,

(e) slope modification,

(f) filtration.

As in the case of the vegetative practices described earlier, combinations of these six categories are prevalent.

Retention

The retention of water is to not only reduce the erosive power of water, but is to permit the settlement of the sediment load. There are many different types of retaining devices, but the most common is probably the sediment trap or basin (sediment settler). A sediment settler can range from a simple hole in the ground in a drainage channel to an elaborate pond complete with an earthen dam and a spillway controlling a water area of up to one acre. In all cases, the objective is the same: to remove unwanted sediment. The effectiveness of the larger sediment settlers in the removal of the smaller sized particles is vastly greater than the smaller settlers. The cost of such settlers is often justified, however, by the need to reduce the sediment load to an extent that it will have a minimum effect on downstream water quality.

Sediment settlers can also be made from gabions [15], straw bales [16], sandbags [15], and possibly logs. It may be noted that the use of gabions and straw sediment basins also make use of a filtering principle, but is should be pointed out that the pores in such a filtering mechanism soon clog with sediment so that the structure more properly acts as a dam. Reference [17] provides good examples on how to relate the size of the sediment settler to the design storm.

Diversion

The purpose of diverting water is to prevent flowages onto and over areas of the job where erosion might be particularly damaging. Diversions can be used to intercept storm water before it reaches disturbed slopes or other exposed areas. They can also be used to collect runoff and convey it to a sediment settler.

Generally, diversions are created by the earth-changer by the shaping of soil surfaces so as to direct water to a desirable location. The use of terraces and benches in steep cuts serves to prevent the increase in the concentration of water as it flows down the slope by collecting it on the terrace or bench and taking it to a suitable outlet. Otherwise, the concentration and high velocity that would be experienced near the base of the cut would result in deeper rills or gullies. The use of diversion applies the second principle mentioned above - make the water walk, not run. At the same time, the retention of sediment can be accomplished if the diverted water is made to move slowly along the terrace or bench.

The creation of a diversion can easily be accomplished by the use of an earth grader to grade a furrow of earth above a particularly erodible area. The water is taken along the base of such a furrow and deposited at a location where the concentration and velocity of water can be safely taken down the slope by way of a downpipe or channel without causing damage through the creation of gullies.

Diversion can also be created by the use of corrugated steel pipes cut lengthwise and anchored in the preformed diversion, by the use of rip-rap, gabions installed over a suitable filter blanket, or, in temporary situations, by the use of properly anchored sod. A recent development has been the use of filter blanket alone in ditch bottoms.

A common use of diversions is to relocate stream courses around a work area. Although the construction of such a diversion will result in some turbidity, the degree of turbidity will be largely determined by the procedures used and the degree of consideration of erosion protection applied to the diversion.

Energy attenuation

Energy attenuation devices are commonly used in engineering practice; these applications although designed and used to prevent the damage to structures by erosion, will not be dealt with here. The second principle of making water walk is involved. Any mechanical technique that will slow the water velocity is an energy attenuating device. A common example is the use of rip-rap in steep ditches while sod is often

used in ditches with a lower gradient. In such applications, the rocks or the blades of grass serve to slow the velocity of water. At the same time, these materials prevent the transfer of energy to soil particles with their consequent movement in the erosion process.

Where long, steep gradients are involved, energy attenuations are commonly constructed by imbedding bricks, concrete blocks or rocks into the concrete or asphalt ditch lining so that the force of water moving down the slope drain will be retarded and its energy attenuated.

The use of check dams, weirs and drop spillways made of a variety of materials, both temporary and permanent, will reduce channel grade and dissipate the energy of flowing water.

Special care has to be taken that the energy attenuation device will adequately dissipate the energy of the water so not to damage banks or the toe of the structure. It should be noted that energy attenuation devices frequently result in a concentration of the volume of the water flow with a consequent increase in water velocity at the structure and, therefore, banks around grade control structures often require additional stabilization measures.

Surface modification

Mechanical means reduce soil erosion through the modification of the surface so as to prevent the transfer of energy between moving water to individual soil particles. A variety of materials are commonly used. Crushed stone, although expensive, might be used especially in those locations where such a material might form the base of proposed roadways, parking areas, etc. The use of such material, however, would be inappropriate where the anticipated land use was for lawns, parks, etc. where a grass sod was the desired cover.

The use of plastic sheeting to prevent dislodgement of soil through rain drop impact has been used; for example, during the construction of the C.N. Tower. The use of this technique, however, must consider the practical aspects; holes in the plastic cover might allow a concentrated flow onto the soil beneath the sheeting unless adequately anchored, and the placement and maintenance might result in higher costs than perhaps the use of vegetative covers.

Other means of surface modification include the compaction of soils on slopes and the creation of depressions by means of equipment cleats in addition to compaction. The techniques which fall into this category involve the reduction of the K factor of the U.S.L.E. Accordingly, these techniques are applicable only to those soils which can be compacted as compaction will lower the K factor.

The use of paving materials will accomplish the same objective.

Slope modification

In those circumstances where steep slopes will result in an unacceptable level of erosion, the flattening of those slopes should be considered as an erosion control practice. The use of retaining walls incorporated into a slope will allow the flattening of slopes above and below the structure within the same horizontal cross-section. Where slopes are steep and it is possible to flatten such slopes to blend into the development, this technique will certainly reduce the LS factor in the U.S.L.E. with a consequent reduction in erosion potential.

It should be noted that the incorporation of a grade control structure into a stream not only serves as an energy attenuator but reduces stream gradient upstream and downstream of the structure.

Filtration

The use of filtration techniques frequently involves the retention of water so that sediment carried in water is removed as the water seeps through the filtering media.

One common and inexpensive application of this technique involves the blockage of a temporary water flow with a truck load of granular material. The granular material (eg. Granular A or B) will act as a dam and will result in the creation of a head of water which will allow the passage of water through the granular material. The sand content of the granular will tend to retain sediment. It should be noted that the granular material will eventually become clogged so that the granular will increasingly become more efficient as a sediment basin. The danger exists, however, that as the granular becomes clogged with sediment, the head of water will increase with the consequent possibility of flowages around the structure.

A recent application of the filtering mechanism involves the erection of filter cloth vertically on a fence in such a way that water carrying sediment is impounded behind such a fence and is filtered as it passes through the filter cloth. Again, as the pores of the filter cloth become clogged, the structure increasingly behaves as a dam causing the settlement of sediment.

Chemical

Various chemical means have been developed which will change the properties of the soil surface generally by aggregating the fine soil particles into larger aggregations. Thus the K factor of the U.S.L.E. is reduced. One chemical formulation is a mixture of fractionated plastic in a glue-like liquid. The mixture, when sprayed on soil aggregates the soil particles but allows the passage of water into the soil especially in those places where slight ponding occurs. It has been found that the use of this material is not effective where large stones predominate in the cut (ie. stony tills). It is probably more effective where soil particle sizes are rather uniform and small.

The use of an asphalt tack in conjunction with a vegetative mulch has already been discussed. An asphalt tack, however, can be used without a mulch. Such an application, however, may not present an aesthetic appearance, especially in an urban area.

Synthetic materials, such as fibreglass, are sometimes used as a substitute for vegetative mulches. Such materials, however, are not readily biodegradable and may create long term aesthetic and maintenance problems.

Management Practices

Although each technique described previously will prevent or reduce the extent of erosion and sedimentation, the right technique has to be used at the right time, the right place, for the right reason and by the right person. This could be called the Principle of the Five Rights. Its application is good management.

The right technique

Of the many different types of erosion and sedimentation control techniques, that technique which is most appropriate to the conditions under which it will operate should be selected. Such a selection will involve a knowledge of the physical and climatic conditions of the site as well as a knowledge of the effectiveness of each technique. The cost of the technique in terms of installation and maintainance costs will also have to be considered. By the judicious combination of the physical site inventory and the cost-effectiveness information, that technique which will do the job at the least cost can be determined.

The right time

Each technique has a time interval in which it is most effective in minimizing the amount of erosion or sedimentation. If applied at the wrong time, the application of the technique may be next to useless. Of what value is seeding and mulching in erosion control when applied at the end of the job when the initial grading was conducted six months earlier and remained exposed until final trim? This is an example of the wrong time to apply an erosion control technique and expect top effectiveness.

The right place

The right technique applied where it will be most effective will be a credit to the development manager; the effective functioning of the technique and the quality results will be readily noticeable. On the other hand, consider the manager who decided to apply sod to a steep slope drain rather than rip-rap and ended up with a damaged slope with still no protection after the first rain! The manager must know not only the various techniques that can be used, but also must know where they will be most effective as well as ineffective.

The right reason

The manager must know how each technique operates in order that he might apply it to get the best results. In effect, he must know why he should apply a given technique under various conditions. He must

be able to describe logically his erosion and sedimentation control program each day; he must know why the sediment basin must be cleaned when it is one-half full and he must know why the sediment basin installed before the drainage enters the natural watercourse is there. And of equal importance, he must be able to identify needs for erosion or sedimentation control that give rise to reasons for installing a technique.

The right person

In the operation of a project, each person has several responsibilities; erosion and sedimentation control should be a responsibility of everyone on the job in the same way that safety is everyone's responsibility. Such responsibilities are not restricted to those who work in the field, but also extend to the planners and the designers.

Although everyone connected with the project should have the responsibility for erosion and sedimentation control, certain people have certain functions. The planners must be able to adequately anticipate areas sensitive to erosion and sedimentation so as to take such problem areas into consideration in the creation of the overall layout. Likewise, the designers must be able to identify problem areas related to the proper sizing of riser pipes and spillways in sedimentation settlers or the proper specification for rip-rap in steep slope drains. The manager of the project in the field has the functions of having the materials available to do the job, and of ensuring that the workers know what is to be done. And lastly, the workman must perceive himself to be an important component in erosion and sedimentation control.

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I

EROSION CONTROL MEASURES

ROADWAY DITCHES

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Check Dams	Structure used to stabilize grade or to control head cutting in natural or artificial channels.	To reduce or prevent excessive erosion by reduction of velocities or by providing partial lined channel sections or structures that can withstand high flow velocities.	Maintain low velocities. Catch sediment. Can be constructed of logs, shot rock, lumber, masonry, or concrete.	Close spacing on steep grades. Require clear-out. Unless keyed at sides and bottom erosion may occur.	Low to High	High
Sediment Barriers	Temporary barriers or diversions that are constructed of sandbags or straw bales.	Retain sediment on site by retarding and filtering storm runoff.	Can be located as necessary to collect sediment during construction. Clean-out often can be done with on the job equipment. Simple to construct.	Little direction on spacing and size. Sediment disposal may be difficult. Specifications must include provisions for periodic clean-out. May require seeding, sodding or pavement when removed during final clean-up. Target for vandals. Of little value in roadside ditches with even slight grades. Must be replaced when rotten or disintegrating.	Low to Medium	Medium
Filter Berm	Temporary ridge of gravel or crushed rock.	Retain sediment on-site by retarding and filtering runoff in ditches prior to roadway paving and establishment of permanent ground cover.	Formal design not required.	Removal of trapped sediment and clean-out or replacement of clogged filter material after each storm.	Low	Medium
Sediment Retention Basin	Temporary dam or basin or a combination of both.	Trap and retain sediment generated during construction activities on-site.	Can be located as necessary. Simple to construct.	Little direction on spacing and size. Sediment disposal may be difficult. Periodic clean-out required. May require seeding, sodding, or pavement when removed during final clean-up. Fine sediment will not settle out in basins with short detention periods.	Low to Medium	Medium to High

ROADWAY DITCHES CONTINUED...

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Ditch Inlets	A catch basin in the ditch.	To redirect surface runoff into storm sewer system.	Sediment can collect in sumps.	Expensive. Care taken to prevent erosion at outlet of sewer pipe. Does not filter out fine material as retention time too short.	High	High
Sodding	Stablizing ditches with grass sod.	To stablize the ditch, to reduce damages from sediment and runoff to downstream areas.	Easy to place with a minimum of preparation. Can be repaired during construction. Immediate protection. May be used on sides of paved ditches to increase capacity.	Requires water during first few weeks. Sod not always available. Will not withstand high velocity or severe abrasion from sediment load.	Medium	Low-Medium
Seeding/Mulching	Application of seed with an organic or inorganic material mixed in to facilitate germination and hold the seed in place.	To provide vegetative covering as early as possible to reduce erosion. The mulch provides temporary erosion protection until grass is established.	Usually least expensive. Effective for ditches with low velocity.	Will not withstand medium to high velocity.	Low	Medium to High
Paving, Riprap, Rubble	Lining ditches with pavement, riprap, or rock rubble.	To prevent ditch erosion where high flow velocities are expected.	Effective for high velocities. May be part of the permanent erosion control effort. Minor repairs relatively easy.	Cannot always be placed when needed because of construction traffic and final grading and dressing. Initial cost is high.	High	High in preventing ditch erosion. Low for retaining sediment.
Erosion Check	Porous, mat-like material installed in a slit trench oriented perpendicular to direction of flow in ditch.	Prevents formation of rills and gullies by permitting subsurface water migration without removal of soil particles and by providing positive grade control of subsurface flow.			Low	Medium
Half-Culvert (Spillways)	A half section of corrugated steel pipe placed in a ditch.	To prevent erosion of ditch itself.		Energy dissipators and sedimentation basins often required. Steel pipe may become undercut such that function as a control factor is completely lost. Erosion may occur at outlets unless precautions taken. Sediment entering it is carried straight through.	Medium	Medium

III

ROADWAY DITCHES CONTINUED......

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Sub-drains Perforated Steel Pipe	Pervious back filled trenches containing a pipe with perforations or open joints for the purpose of intercepting ground water or seepage.	Used to draw off surface water, lowers water table, reduces seepage.	Reduces erosion hazard in ditch by reducing surface water flow.		Medium	High
Excelsior Blanket	Protective blanket used in the establishment of vegetation in critical areas.	As a mulch it conserves soil moisture, serves as an insulator against intense solar insolation, dissipates energy from falling raindrops and reduces erosion caused by overland flow.	Resistant to erosion by concentrated storm runoff. Can be used in critical areas such as swales, ditches, steep slopes, highly erodible soil etc.	Poor adherence to soil.	Very High	Medium
Fiberglass Matting	Flexible fiberglass made of inorganic materials that will not rot, corrode or burn.	Used in construction of erosion checks and as a mulch for seedbeds.	Can be used as a mulch blanket where long-term resistance to erosive forces is desired in conjunction with vegetation.	Poor adherence.	Very High	Medium
Glassroot	Fiberglass mulch product for use on newly seeded areas.	As a mulching product it conserves soil moisture, insulates against intense solar energy, dissipates energy from falling raindrops and reduces erosion caused by overland sheet flow.	Will not react or decompose when exposed to water, sunlight or chemicals found in the soil.	Difficult to handle.	Very High	High
Jute Netting	Heavy woven jute mesh of rugged construction used in establishment of vegetation.	As a mulch, conserves soil moisture, insulates against intense solar isolation, dissipates energy from falling raindrops and reduces erosion caused by overland flow.	Can withstand the higher flow velocities associated with critical swales, ditches, median strips etc.	Use of erosion checks in conjunction may be required. Unavailable.	Very High	High
Mulch Blankets	Composite of cellulose fibers bonded together into a blanket to be used in establishment of vegetation in critical areas.	As a mulching product, conserve soil moisture, insulate against intense solar radiation, dissipate raindrop energy, and reduce erosion caused by overland flow.		Cost of application high.	Very High	Medium

ROADWAY DITCHES CONTINUED......

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Netting	Natural or synthetic fiber mulch securely anchored on seeded areas or areas temporarily stabilized with mulch tacking products which are insufficient.	To hold seed in place and also to reinforce newly placed turf that may be subject to severe runoff velocities before turf has taken proper hold.		Not flexible. After growth started, ineffective as erosion control.	Very High	Medium
Plastic Filter Sheet	Cloth woven of polypropylene monofilament yarns secured to soil surface with securing pins and staples with fiberglass rods.	Replacement for graded filter systems and filter blankets in conjunction with many hydraulic structures.		Poor adherence to soil.	High	Medium
Straw or Hay	Straw or hay used as a mulch product on newly seeded areas or as a temporary measure to protect bare soil areas that have not been seeded.	As a mulch, conserves soil moisture, insulates against intense solar energy, dissipates raindrop energy and reduces erosion caused by overland flow.	Can be applied by hand spreading on small plots and by mulch blowing equipment on larger areas.	Straw and hay mulch should be tacked to protect against wind and water erosion. Concentrated flow will wash straw and hay off.	Low	Medium
Woodchips	Chips of wood produced by processing tree trunks, limbs, branches etc. in wood chipping machines.	1. Temporary or interim erosion control technique to protect bare soil areas that have not been seeded. 2. Mulch product on newly seeded areas.	Useful as a mulch when used with late fall seeding operations that require protection over winter. Reduce amount of open burning.	Equipment availability. Do not produce good growth.	Medium Medium	High Low

V

ROADWAY SURFACE

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Crowning to Ditch or Sloping to Single Berm	Grading the road so that run-off flows off into ditch or a berm.	Directing surface water to a prepared or protected ditch to minimize erosion control runoff.	Easy to construct.	None - should be part of good construction procedures.	Low	High
Compaction	Mechanical compressing of subgrade or granular courses to optimum density.	To reduce erosion, loose or uncompacted material is more subject to erosion. Final lift of each day's work should be well compacted and bladed to drain to ditch or berm section.		None - should be part of good construction procedures.	Low	High
Aggregate Cover (Gravel Sheeting)	Blanket of granular material on roadway surface.	Provide a material which is not easily eroded.	Minimizes surface erosion. Permits construction traffic during adverse weather.	Requires working and compaction if exposed for long periods of time. Loss of surface aggregates can be anticipated.	High	High
Filter Berm	Temporary ridge of gravel or crushed rock constructed across a graded right-of-way that is not subject to vehicular traffic.	Retains sediment on-site by retarding and filtering run-off while at the same time allowing construction traffic to proceed along right-of-way.	Easy to construct.	Removal of trapped sediment and cleanout or replacement of clogged filter material after each storm.	Low	Medium
Interceptor Dike	A temporary ridge of compacted soil constructed across a graded right-of-way that is not subject to vehicular traffic.	Reduce erosion by intercepting storm runoff and diverting it to temporary outlets where it can be disposed of with minimal erosion.		Inspect after each storm. Repairs must be completed before next storm to ensure against structural failure.	Low	Medium
Paved Gutter	Paved asphalt gutters constructed at the outer edge of the paved shoulders.	To protect shoulders on steep grades and prevent erosion of the slopes.		Erosion control such as slope drains or catch basins required at outlet.	Medium	High

VI

CUT SLOPES

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Berm top of cut.	Earth ridge constructed along top edges of embankments.	To divert water from cut slope and collect it for slope drains/paved ditches.	May be constructed before grading is started. Minimizes disturbance of existing vegetation when used rather than diversion terraces.	Access to top of cut. Difficult to build on steep natural slope or rock surface. Concentrates water and may require channel protection or energy dissipation devices. Can cause water to enter ground, resulting in sloughing of the cut slope.	Low	Medium to High
Diversion Dike	A temporary ridge of soil constructed at top of cut or fill slopes combined with a crown ditch to intercept surface runoff from the slope above and conduct it to slope drains or natural water courses on milder slopes.	Collects and diverts water from cut slope to reduce erosion.	May be incorporated in the permanent project drainage.	Access for construction. May be continuing maintenance problem if not paved or protected. Disturbed material or berm is easily eroded.	Low	Medium to High
Slope Benches	Large steps or benches cut into slope.	To slow velocity of surface water and collect sediment.	Provides access to slope for seeding, mulching and maintenance. Collects water for slope drains or may divert water to natural ground.	May cause sloughing of slope if water infiltrates. Requires additional right-of-way. Not always possible due to rotten material etc. Requires maintenance to be effective. Increases excavation quantities.	Medium	Low to Medium
Slope Drains (Pipe, Paved etc.)	A channel of concrete, pipe etc. to conduct surface runoff from the top of a slope to the bottom of the slope.	To collect surface water and thereby reduce erosion on the slope.	Can be temporary or part of permanent construction. Can be constructed or extended as grading progresses.	Requires supporting effort to collect water. Permanent construction is not always compatible with other project work. Usually requires some type of energy dissipation.	High	High
Seeding/Mulching	Application of seed with an organic or inorganic material mixed in to facilitate germination and hold the seed in place.	To provide vegetative covering as early as possible to reduce erosion. The mulch provides temporary erosion protection until grass is rooted.	Temporary or permanent seeding may be used. Larger slopes can be seeded and mulched with smaller equipment if stage techniques are used.	Difficult to schedule high production units for small increments. Time of year may be less desirable. May require supplemental water.	Low	High once grass established.

CUT SLOPES CONTINUED......

TREATMENT PRACTICF	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Seeding / Mulching Continued...........				Contractor may perform this operation with untrained or unexperienced personnel and inadequate equipment if stage seeding is required.		
Sodding	Stabilizing erosive areas with grass sod.	To stabilize slopes immediately, thereby reducing erosion.	Provides immediate protection. Can be used to protect adjacent property from sediment and turbidity.	Difficult to place until cut is complete. Sod not always available. May be expensive.	Medium	Medium to High
Slope pavement, riprap.	Covering the slope with a layer of pavement or riprap.	To provide immediate protection for high risk areas and order structures.	May be cast in place or off site.	Expensive. Difficult to place on high slopes. May be difficult to maintain.	High	High
Granular Blanket	A 1' to 2' thick blanket of material such as Granular Base Course Class "B" placed evenly over the surface of slopes comprised of very erosive soils.	To provide a stable, free draining slope material. Particularly suitable when ground water emerges through the surface soil.			High	High
Temporary Plastic Cover	Plastics in wide rolls and large sheets placed over slope.	To provide temporary protection for cut or fill slopes.	Easy to place and remove. Useful to protect high risk areas from temporary erosion.	Provides only temporary protection. Original surface usually requires additonal treatment when plastic removed. Must be anchored to prevent wind damage. If not properly anchored at top, water will travel over slope under the plastic.	High	Medium to High
Serrated Slope	Steps cut to the contour in soft rock cuts.	To lower velocity of surface runoff and collect sediment. Aids in establishment of vegetated cover on decomposed rock or shale slopes.	Holds moisture. Minimizes amount of sediment reaching roadside ditch.	May cause minor sloughing if water infiltrates. Construction compliance.	Low	Medium

CUT SLOPES CONTINUED.......

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Level Spreader	An outlet constructed at zero grade across a slope where concentrated runoff may be spread at non-erosive velocities over undisturbed areas stabilized by existing vegetation.	To convert concentrated flow into sheet flow for outlet at non-erosive velocities onto areas stabilized by vegetation.	Formal design not required.	Outlet lip must be exactly level and uniform from end to end or concentrated flow and consequent erosion of stabilized area will result. Only built where spreader on undisturbed soil and where area directly below level lip is stabilized by vegetation.	Low	Medium
Intercepting Ditch	Ditches constructed in the form of benches in the cut slope.	To check velocity of flow on the slope and thereby control erosion.			Medium	High
Subdrains (Perforated pipe)	Pervious backfilled trenches containing a pipe with perforations or open joints for the purpose of intercepting ground water or seepage.	Used to draw off surface water. Lowers water table, reduces seepage. Partly directed toward slope stability and erosion control.		Pipe may become filled with sediment.	Medium	High
Roughness and Scarification.	Roughness is the uneven or bumpy condition of the soil surface. Scarification is the process of loosening or stirring the soil to shallow depths without turning it over.	Slows down flow velocity and enhances water infiltration.	Improves seeding and sodding success.		Low	Medium
Chemical Soil Stabilizers, Mulches and Mulch Tacks	Chemical emulsions sprayed on denuded surfaces, seeded and mulched surfaces or mixed in with seed/mulch mixture.	1. Temporary soil stabilization. 2. Chemical mulch. 3. Mulch tack.	Can be used to protect denuded soil from wind and water erosion during delays in grading operations during hot and dry periods, after final grading, or until permanent seeding is possible.	Special spray equipment required. Cannot be applied in subfreezing weather.	Medium	High
Fiber Mulches) Mulch Blankets and) Nettings)	SEE ROADWAY DITCHES					

FILL SLOPES

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
(Diversion Dike) Berms at Top of Embankment.	Earthen or soil cement dikes constructed along shoulders of roadways.	To prevent runoff of embankment surface from flowing over fill slopes and thereby reduce erosion hazard.	Collect runoff for slope drains or protected ditch. Can be placed as a part of the normal construction operation and incorporated into fills or shoulders.	Cooperation of construction operators to place final lifts at edge for shaping into berm. Failure to compact outside lift when work is resumed. Sediment buildup and berm failure.	Low	Medium to High
Slope Drains	Channels of concrete, pipe etc. to conduct surface runoff from the top of slope to the bottom of the slope.	To prevent fill slope erosion caused by embankment surface runoff.	Can be constructed of full and half section pipe, bituminous, metal, concrete, plastic, or other waterproof material. Can be extended as construction progresses. May be either temporary or permanent.	Permanent construction as needed may not be considered desirable by contractor. Removal of temporary drains may disturb growing vegetation. Energy dissipation devices required at outlets.	High	High
Fill Berms or Benches	Large steps or benches constructed on a fill slope.	To slow velocity of slope runoff and collect sediment.	Provides access for maintenance. Collects water for slope drains. May utilize waste.	Requires additional fill material if waste is not available. May cause sloughing. Additional right-of-way may be required.	Low	Low - Medium
Seeding/Mulching	Application of seed with an organic or inorganic material mixed in to facilitate germination and hold the seed in place.	To reduce erosion by providing a protective cover thereby decreasing the period a slope is left bare.	Mulch that is cut in or otherwise anchored will collect sediment. The furrows made will also hold water and sediment.	Seeding season may not be favourable. Not 100% effective in preventing erosion. Water may be necessary. Steep slopes may require supplemental treatment.	Low	High when vegetation established.
Sodding	Stabilizing silt - producing areas with grass sod.	To stabilize the area, to reduce damages from sediment and runoff to downstream areas.	Provides immediate protection.	Material not always available. Application during dry periods requires additional care. Sod may slump.	Medium	Medium to High
Roughness and Scarification.	To roughen slope surface by discing and light scarification	Slows down flow velocity and enhances water infiltration.	Improves seeding and sodding success. No special equipment required.		Low	Medium

FILL SLOPES CONTINUED.....

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Chemical Soil and Stabilizers, Mulches and Mulch Tacks	Chemical emulsions used as temporary soil stabilizers, mulches and mulch tacks.	1. Temporary soil stabilization. 2. Chemical Mulch. 3. Mulch Tack.	Can be used to protect denuded soil from wind and water erosion during delays in grading operations during hot and dry periods, after final grading or until permanent seeding is possible.	Special spray equipment required. Cannot be applied in subfreezing weather.	Medium	High
Fiber Mulches,) Mulch Blankets and) Nettings)	SEE ROADWAY DITCHES					

PROTECTION OF ADJACENT PROPERTY

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Brush Barriers	A barrier consisting of slashing, logs etc.	To create deposition of sediment in small fans below embankment areas.	Use slashing and logs from clearing operations. Can be covered and seeded rather than removed. Eliminates need for burning or disposal off right-of-way.	May be considered unsightly in urban areas. May be washed away in heavy rain storm.	Low	Low
Straw Bale Barriers	A barrier composed of staked straw bales.	To reduce velocity of runoff and filter sediment and some turbidity from runoff.	Straw is readily available in most areas.	Require removal. Subject to vandal damage. Flow is slow through straw requiring considerable area.	Low	Medium
Sediment Traps	Temporary dam or basin or a combination of both that will trap and store sediment produced on exposed areas and delivered to the structure by storm runoff.	Trap and retain sediment generated during construction activities on-site.	Collect much of sediment spill from fill slopes and storm drain ditches. Inexpensive. Can be cleaned out and expanded to meet need.	Does not eliminate all sediment and turbidity. Space is not always available. Must be removed (usually). Requires continuous clean out during construction.	Low	Medium
Sedimentation Basin	A temporary or permanent larger form of a sediment trap with standup pipe, emergency spillway etc.	To trap and store sediment from erodible areas in order to protect properties below the installation from excessive siltation.	Can be designed to handle large volumes of flow. Both sediment and turbidity are removed. May be incorporated into permanent erosion control plan.	Require prior planning, additional right-of-way and/or flow easement. If removal necessary, can present a major effort during final construction stage. Clean out volumes can be large. Access for clean out not always convenient.	Medium to High	High
Energy Dissipators	A structure such as concrete or wooden baffles used to reduce velocity of concentrated flows before they carry onto adjacent property.	Slow velocity to permit sediment collection and to minimize channel erosion off project.	Can be part of permanent erosion control. Durable.	Collect debris and require cleaning. Require special design and construction of large shot rock or other suitable material from project.	Low High if ditch included.	High
Level Spreaders	An outlet constructed at zero grade across a slope where concentrated runoff may be spread at non-erosive velocities over undisturbed areas stabilized by existing vegetation.	Convert collected channel or pipe flow back to sheet flow.	Avoid channel easements and construction off project. Simple to construct.	Adequate spreader length may not be available. Sodding of overflow berm is required. Must be part of a permanent erosion control effort. Maintenance forces must maintain spreader until no longer required.	Low	Medium

PROTECTION OF ADJACENT PROPERTY CONTINUED.......

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Vegetative Filter Strip	An area of vegetative cover through which storm water must flow before it enters streams, storm sewers, conduits, adjacent property etc.	Remove some sediment from runoff water by filtering and by gravity sedimentation as the flow velocity is reduced.	Filter strips can be naturally occurring or man-made. Preservation of area only maintenance often required.	High flows could cause gully erosion. May require additional right-of-way to be effective.	Low	Medium

PROTECTION OF SURFACE WATER

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Construction Dike	An earth dam or dike to restrain water from a construction site in the water.	1. To keep work site dry. 2. To decrease turbidity.	Permits work to continue during normal stream stages. Controlled flooding can be accomplished during periods of inactivity.	Usually requires pumping of work site water into sediment pond. Subject to erosion from stream and from direct rainfall on dike. Removal a major problem.	Low	Medium
Coffer Dam	A barrier built in the water so as to form an enclosure from which the water is pumped to permit free access to the area within.	1. To allow dry site conditions. 2. To decrease turbidity.	Work can be continued during most anticipated stream conditions. Clear water can be pumped directly back into stream. No material deposited in stream.	Expensive.	High	High
Temporary Stream Diversion	Temporary changing the channel or course of a stream.	To allow construction of culverts etc. in the dry. Reduces erosion hazard as work not done in running water.	Prepared channel keeps normal flows away from construction.	New channel usually will require protection. Stream must be returned to old channel and temporary channel refilled.	Medium to High	Medium to High
Riprap	Rock fragments lining bottoms and banks of surface waters.	To prevent erosion of surface water channel banks and bottoms.	Sacked sand with cement or stone easy to stockpile and place. Can be installed in increments as needed.	Expensive. Displace sediment when dropped into stream.	High	Medium
Temporary Culverts for Haul Roads	Pipe culverts placed at stream crossings of haul roads until completion of construction.	To eliminate stream turbulence and turbidity. To allow normal flow of surface water.	Provide unobstructed passage for fish and other water life. Capacity for normal flow can be provided with storm water flowing over the roadway.	Space not always available without conflicting with permanent structure work. May be expensive especially for larger sizes of pipe. Subject to washout.	Low to High	Medium
Rock-Lined Low-Level Crossing	Porous rock fill placed in shallow streams to permit equipment crossing.	To minimize stream turbidity.	Inexpensive. May also serve as a ditch check or sediment trap.	May not be fordable during rainstorms. During periods of low flow passage of fish may be blocked.	Low	Medium

PROTECTIVE SURFACE WATER CONTINUED.......

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Check Dam	A structure used to stabilize the grade or to control head cutting in natural or artificial channels.	To reduce or prevent excessive erosion by reduction of velocities in watercourses or by providing partial lined channel sections or structures that can withstand high flow velocities.	Maintenance generally not required.	Could eventually silt in.	Low	High
Fabri-form Erosion Control Mats	Technique for pressure injecting fluid-mortar into flexible fabri-forms.	Provide structure, slope and grade protection both above and below the water line.	Can be used in shoreline stabilization, levee facing, channel lining, and construction of revetments and check dams. Uninterrupted storm flow.		Medium	High
Gabions	Large, multi-celled, rectangular wire mesh boxes filled with rock.	Used for construction of erosion control structures such as revetments, retaining walls, check dams, etc.	Effective as filters for coarse debris.	Limited success in filtering out fine sediments such as silt.	High	Medium to High
Plastic Curtain	A heavy plastic curtain placed in a shallow semicircle from the shore, hanging from polyurethane floats and anchored with sandbags.	To trap sediment produced from construction activities on adjacent shoreline. Reduce stream turbidity.				
Grade Control Structure	Earth embankments with pipe spillways or mechanical structures of concrete, masonry, steel, aluminum or treated wood.	Prevent excessive velocities in channels by reducing channel slope.		Safety hazard to traffic. Some of most effective structures quite costly. Vulnerable to failure. Possible scouring at ends.	High	High
Cement Lining	Permanent cement lining of watercourse.	Prevent shoreline erosion.			High	High

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PROTECTION OF SURFACE WATERS CONTINUED.........

TREATMENT PRACTICE	DEFINITION	OBJECTIVE	ADVANTAGES	PROBLEMS	COST RATING	EFFECTIVENESS RATING
Sandbag Stream Check	A dam of sandbags, placed across a small stream.	To reduce flow of water, causing sediment created by upstream construction activities to be deposited.	Easily constructed. Easily repaired.	Permanent flow will reduce its effectiveness by rapid sedimentation. Will wash out with high flows. Only useful in intermittent and very small streams.	Low	Medium
Gavion Sediment Traps	A dam across a stream composed of gabions.	Filter out sediment.	Can be a temporary measure.	Erosion can occur around and under traps. Filter out large debris quite well but limited success in retaining silt. Current velocities must be low.	High	Medium
Sills	Concrete aprons along shoreline and streambanks.	Streambank and shoreline protection.			High	High
Groins	Low walls of timber, rock, concrete or steel constructed into the water at right angles to the shore of lakes and streams.	To trap sand or other water transported material. Develops beaches and protects shoreline from erosive action of waves and currents.			High	Medium
Restriction on equipment crossing streams.	Minimize number of crossings and permit them only at stable reaches of a stream.	Minimizes streambed disruption.		May necessitate a temporary stream crossing. Contractor may have to travel out of way to transport equipment to other side.	Variable	High

INTRODUCTION TO THE "MANUAL OF PRACTICE ON URBAN DRAINAGE"

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This paper introduces the "Manual of Practice on Urban Drainage". In this presentation, the membership of the Working Committee, their activities and progress are described. The objectives, scope and role of the Manual are clarified. Contents of the Manual are briefly summarized and highlighted.

Draft No. 3 of the "Manual" served as the reference document for this paper.

BACKGROUND

In response to the International Joint Commission recommendations on the need for control of pollution caused by overflows from combined sewerage systems and urban surface runoff, the Urban Drainage Subcommittee was established in 1971 under the Canada-Ontario Agreement to conduct a research and development program on urban drainage management. The program has three phases:

(1) identification of urban drainage problems,
(2) development of capability to solve these problems,
(3) development of strategy for implementing solutions.

Five years have elapsed and over $1.5 million have been expended on about forty research projects covering all aspects of urban drainage from its pollution and hydrological impact through to new methodology and criteria for its control. Considerable progress has been made in both Phases (1) and (2). Although the two phases are still on-going, the Subcommittee is now moving into Phase (3) of the Program. Research and development findings are being consolidated and applied to solve practical drainage problems. Efforts are being directed toward all levels of government and the private sector to adopt new and innovative methods of managing runoff from urban and developing areas. Towards this end, the "Manual of Urban Drainage Practice" has been prepared.

MEMBERSHIP OF THE MANUAL WORKING COMMITTEE

This "Urban Drainage Manual of Practice" has been prepared by a Working Committee with representatives from the Urban Drainage Subcommittee, municipal governments and other agencies of the Ontario government which have either interests or responsibilities related to urban drainage problems. The full membership of the Working Committee is listed on the first page of the Manual and the break-down of the Committee by affiliations is shown in the following:

Environment Canada, Environmental Management Service	= 1
Environment Canada, Environmental Protection Service	= 3
Ministry of the Environment	= 7
Ministry of Housing	= 2
Ministry of Natural Resources	= 2
Ministry of Transportation and Communications	= 2
Municipal Engineers Association	= 2
Nova Scotia Technical College	= 1
United States Environmental Protection Agency	= 1
Total	= 21

Many projects that have been carried out under the Urban Drainage Program are referred to in the Manual. In addition many agencies, consultants and individuals have provided input material to the Manual. Such input will be properly referenced in the final Manual publication.

The efforts of J.F. MacLaren Limited and Paul Theil Associates Limited are acknowledged; they provided, under contract, planning and design examples for the Manual.

There are six chapters in the Manual. Accordingly, the 21 members of the Working Committee are subdivided into six groups; each group is responsible for the input and review of one of the chapters. Each group is under the coordination of a principal chapter writer who compiles and edits the input material and writes the draft chapter. These principal writers are:

Chapter 1:	Urban Drainage Problems	- D.H. Waller
Chapter 2:	Urban Drainage Planning	- D.G. Weatherbe

Chapter 3:	Design Techniques	- J. Marsalek
Chapter 4:	Source Controls	- F.A. Tonelli
Chapter 5:	Collection, Storage and Treatment Alternatives	- F.A. Tonelli
Chapter 6:	Administration and Implementation	- B.R. Ward

OBJECTIVES OF THE MANUAL

The Manual has the following five major objectives:

1) To identify the seriousness of urban drainage problems, their magnitude and impact on the Great Lakes Basin. These problems are both technical and institutional in nature.

2) To identify and describe innovative urban drainage concepts as alternatives to conventional solutions to urban drainage problems, and to provide methodologies for selecting the most cost-effective alternative.

3) To present urban drainage problems and solutions in a framework of interagency cooperation in order to minimize the institutional conflicts between the many government agencies responsible for all aspects of urban drainage.

4) To achieve urban storm water management, i.e. the control and use of storm water in such a manner that the negative effects of urban development are minimized and the beneficial effects are improved. For example, ponds for storm water detention can also be designed to provide a body of water for recreational and aesthetic purposes.

5) To contribute to the achievement of the general and specific water quality objectives for the Great Lakes agreed to by the Governments of Ontario and Canada.

THE SCOPE AND THE ROLE OF THE MANUAL

The Manual is not a design handbook in the sense that it contains all the information needed to plan and design urban drainage systems. Instead, it provides guidance to adoption and implementation of improved urban drainage practices together with many Ontario examples.

It is a first step in an attempt to develop a consistent and coherent approach to the identification and solution of urban drainage problems in Ontario.

Although the Manual reflects the consensus of the Working Committee that includes representatives mostly from the Ontario government, it is by no means an official Ontario government policy on urban drainage. However, it is hoped that the Manual, developed in the context of the Canada-Ontario Agreement, will form the foundation upon which urban drainage policy in Ontario is developed. With appropriate modifications, this Manual can form a basis for future urban drainage policies for the Canadian government and other provincial governments.

The Manual would serve as a useful reference document to town planners, developers, contractors, ratepayers and citizen groups, consultants and government officials of all regulatory agencies involved with urban drainage.

ACTIVITIES AND PROGRESS OF THE WORKING COMMITTEE

The Working Committee was formed in July, 1976. The actual compilation of the Manual started in September and Draft No. 1 was completed in December. Subsequent improvement of Draft No. 1 resulted in the production of Draft No. 2 in February. Copies of Draft No. 2 have been sent to relevent government agencies as well as professional bodies such as the Consulting Engineers Association of Ontario and Municipal Engineers Association for their review and comments. Draft No. 3 was produced at the beginning of March and is now distributed at the Conference for discussion and solicitation of means of its improvement. It is expected that there will be suggestions, ideas, comment and criticism forthcoming from the Conference, and especially from the Panel Discussion Session that will assist in improving Draft No. 3 to a "final version" condition which will be issued in the Canada-Ontario Agreement publication series.

Following the completion of the Manual, the Working Committee will remain standing but re-structured in order to develop the official Ontario government policy and guidelines on urban drainage management using the Manual as the basis. It is estimated that such a policy and guidelines should be completed within the fiscal year 1977/78, and then

be forwarded to senior levels of government for consideration and approval for implementation.

THE MANUAL

This section discusses the Manual including the philosophy of the Committee on which the Manual is based. The contents in each chapter will be briefly summarized and key issues as well as recommendations of the Committee will be highlighted. Finally, deficiency of the Manual in covering some topics of concern will also be mentioned.

For the sake of streamlining this presentation, the chapters will be discussed in the order of 1, 3, 4, 5, 2 and 6. Draft No. 3 of the Manual is available to the Conference delegates. Special reference should also be made to the Introduction paper by Mr. G.H. Mills.

Chapter 1

Chapter 1 describes the urban drainage problems, and has been presented in detail by Dr. Waller at the first day of this conference.

Basically, the first half of this Chapter describes the urban drainage problems that occur in developed urban areas and in developing urban areas, and examines the water quality impacts of urban runoff to the receiving streams and lakes. It also briefly discusses the institutional problems associated with urban drainage control. Then, the emphasis of the second half of the chapter is switched to Ontario. It describes the various drainage problems occurring in Ontario municipalities and their effects on the Great Lakes Basin. Finally, a rough estimate of the cost of urban drainage improvement for Ontario is given.

The urban drainage problems can be summarized into two main categories - technical problems and institutional problems:

(1) Technical urban drainage problems occur in localized areas, and involve both quantity and quality. Quantity problems are such as basement flooding and stream flooding, erosion, depletion of groundwater and reduction of baseflow in streams. Quality problems involve runoff and combined sewer overflows degrading water quality and causing algae growth, siltation, bacteria growth, and low

dissolved oxygen concentration; thus putting stress on aquatic lives in the receiving streams. These aforementioned technical problems are rather immediate, and have to be solved right away.
Long term effects of these problems on the Great Lakes include gradual build-up of heavy metals, pesticides, nutrients, sediments, and salts being washed down by the runoff. These long term effects will also have to be dealt with subsequently by the governments.

(2) The other class of problems is institutional in nature. For example, piece-meal land development within a watershed by individual municipalities or developers will cause downstream flooding as a result of the uncontrolled upstream drainage. Another example of lack of coordination among governments would be: in a municipality, the public sewers are carefully constructed and inspected, but the construction of building sewers, on the other hand, are governed by plumbing codes and sometimes are not well controlled, thus causing infiltration problems.

Chapter 3

From Chapter 1, we learn that there are quantity and quality problems in urban runoff in localized areas. Just what is the magnitude of these quantity and quality problems? and how to estimate them? The purpose of Chapter 3 is to answer these questions.

In this chapter, methods of calculating both the quantity and quality of flow in drainage systems are discussed and the methods are given for both combined sewer systems and storm sewer systems. The difference between these two is that in the combined sewer system, the flow components include not only the storm water, but also the sanitary sewage, industrial and commercial waste, inflow and infiltration. This chapter also examines the changes in distribution and composition of flows when they are routed through the sewer systems. It makes a brief reference to the hydraulic design of sewer systems and recent developments in this field, such as the risk-based design and the optimized design of storm sewer networks. Finally, many computer models for analysis and design of urban drainage systems are discussed and compared in this chapter.

There are several conclusions drawn in this chapter:

(1) The most important one is that, although this chapter is heavily loaded with model simulation, it does not recommend that computer simulation be used in every case.

(2) For estimating quantity of runoff, the Rational method is acceptable if high accuracy is not required and if the design is limited to the sizing of sewer pipes. Hydrological models should be used if higher accuracy is required and if the design includes runoff storage and detention, or water quality aspects.

(3) For estimating quality of runoff, simple empirical formulas are acceptable in a preliminary analysis. A detailed computer analysis of runoff quality will take into account accumulation and washoff of pollutants and, in this case, calibration with field data is desirable.

(4) The accuracy of quality computation is likely to be one order of magnitude lower than the accuracy of quantity computations.

<u>Chapter 4</u>

From the previous two chapters (i.e. Chapters 1 and 3), we learn how to estimate the quantity and quality of urban runoff, and their effects on the receiving waters. The following two chapters, 4 and 5, describe the various control techniques which can be used to minimize these runoff problems. Chapter 4 deals with source control, i.e. to control the quantity and quality of runoff before it reaches the sewer system.

Control of runoff quantity includes on-site detention-retention, such as surface ponds, roof-top storage, parking lot storage, and street storage. It also includes the disposal of roof drain and foundation drain water to land rather than to the sewer system. It includes ways to increase ground infiltration of storm water by having porous pavement on roadways, and on the parking lots, by using open ditches and swales instead curb gutters, and by using french drains.

Control of runoff quality includes erosion control during construction, or no construction permitted in erosion-prone areas such as

ravine slopes. It also includes the control of chemicals application to urban surfaces such as the use of pesticides, fertilizers, and de-icing chemicals. It also considers street cleaning to pick up dirt and animal droppings before they get washed down the sewers by precipitation.

There are several recommendations from this Chapter, and they are:

(1) Source control, in some cases, can be effective and economical, and should be considered as opposed to treatment of storm water.

(2) There is a great tendency to use "ponds" for every case of control. It should be realized that "ponds" are only one aspect of control.

(3) Major-minor design concept, and whenever possible, natural engineering approach should be promoted.

(4) Wherever practical roof drain water may be disposed off on land via splash pads, but making sure that the water will infiltrate into the ground rather than into the weeping tiles.

Chapter 5

The previous Chapter 4 deals with control techniques before the runoff enters the drainage system. Chapter 5 deals with control techniques after the runoff has entered the drainage system, and these techniques are applicable to both storm sewer systems and combined sewer systems. Whenever possible, each technique is illustrated with practical examples together with representative cost data. Canadian experiences in these control techniques are also described whenever applicable.

The Chapter is divided into three sections:

The first section deals with collector system controls, which relate to the interception and transport of storm water or combined sewage within the drainage system. These controls include sewer separation, in-system storage, dynamic flow routing, maintenance of sewer systems to reduce infiltration, and sewer flushing and cleaning including catch basin cleaning.

The second section deals with using storage to control the runoff quantity and quality. These include both in-line and off-line storage. Some storage is designed as detention/sedimentation basins and the water

is then discharged at a controlled rate to the receiving streams; others are designed to serve as temporary storage and the water can be pumped back to treatment plant during off-peak periods.

The third section deals with treatment devices, and has been discussed in Tony Tonelli's paper yesterday (Treatment Technology for Urban Runoff). These include devices such as sedimentation tanks, screening, filtration, flotation, regulator-concentrator, secondary treatment including physical-chemical processes and disinfection. To summarize this Chapter, the following comments can be made:

(1) Technologies already exist to abate storm water and combined sewer overflow pollution.

(2) For small municipalities, the abatement solution, whatever it is, must be simple. For example in the case of treating combined sewer overflow, an off-line storage with pump-back of the water to the treatment plant during off-peak periods may be a possible answer, if land is available for storage.

(3) For large municipalities, many options are open, including dynamic flow routing, storage, sewer separation and specialized wet weather treatment devices.

(4) Whenever possible, non-structural measures should be considered, and these include sewer flushing and cleaning, and street and catch basin cleaning.

(5) With so many alternative abatement solutions available, it would appear that a cost-effective evaluation is essential in order to select the optimum alternative, and this is done by a planning approach as discussed in Chapter 2.

Chapter 2

Basically, the steps in the planning approach as described in this Chapter are very simple. They include:

(a) defining the problem, (b) establishing the evaluation criteria, (c) defining the system components, (d) formulating alternatives, (e) selecting the alternative that best fits the criteria, and then, (f) implementing the selected alternative.

To illustrate this planning approach further, an over-simplified example is given in the following:

Step (a): Suppose the problem is to put in control measures to minimize the effects of runoff from a new subdivision.

Step (b): Suppose we have three evaluation criteria, and they are: the water quality of the stream receiving the runoff must be fit for swimming; the runoff must not disrupt aquatic life; and the control measure must be at the least cost.

Step (c): Now we go ahead to collect rainfall and snowmelt and land-use data and estimate the volume and rate of runoff, as well as the pollutant and bacteria concentrations in the runoff.

Step (d): Based on these data, we may formulate several alternative control measures: e.g. we may use ponds, or roof-top and parking lot storage; or we may collect runoff in a downstream storm tank, and then treat and disinfect the effluent from the storm tank.

Step (e): With all these options at hand, now we can test each alternative against the criteria.

The second alternative, which is to collect, treat and disinfect the runoff, may satisfy the swimming criterion, but the effluent may be toxic to aquatic life, and it may be costly. The first alternative which is to use simple ponds may be cheap, but the effluent from the pond may pollute the receiving stream and make it unfit for swimming.

By using this testing process, we can finally decide on an alternative which will best fit all the criteria, and in this case, it may be a combination of ponds, roof top and parking lot detention.

Step (f): After we have decided on the alternative, then we can draw up schedules for its implementation.

This basic planning approach can be used for selecting control measures for simple cases, such as the one just described, or it can be used for complicated cases, such as the planning of control measures for the whole watershed. In that situation, there will be

multi-objectives and criteria with many combinations of alternatives. Computer modelling may then be required.

The purpose of Chapter 2, then, is to detail this planning approach to select optimum alternatives to solve urban drainage problems.

The chapter starts by stating some general planning considerations and concepts based on the flood control objectives of the Ministry of Natural Resources and the environmental objectives of the Ministry of the Environment. It then details the sequence of activities involved in formulating a master drainage plan for a developing watershed, a total environmental management plan for an existing municipality, such as the St. Thomas Demonstration Project discussed yesterday, and a flood relief plan for a small portion of a city. This Chapter then goes on and describes what preventive measures should be considered in new urban development planning and what remedial measures can be considered in existing municipalities. Finally, some planning examples in Ontario are also documented in this chapter.

There are several general recommendations coming out of this Chapter:

(1) Planning should include as large an area as possible. Ideally, watershed planning should be carried out, so that the effects of drainage from various sub-sections of the watershed can be put into perspective; thus effective control measures can be installed at strategic locations.

(2) Planning should start as early as possible, preferably at the pre-development stage, because at that stage many options for control are available, and preventive measures are always cheaper than remedial measures.

(3) Planning should involve as many relevant agencies as possible. Proper liaisoning with these agencies should be maintained so as to promote interagency cooperation and minimize their conflicts.

In addition, there are more considerations recommended in the planning of <u>new developments</u>. They are:

- Regional planning and watershed planning are required wherever practical.
- Integrate land-use planning with urban drainage planning.
- Erosion and sedimentation should be controlled during and after construction. Level of control is site-specific and based on environmental protection. In general cases, ponds and sediment traps may be adequate. Re-vegetation after construction may be desirable. Construction should not be permitted in erosion-prone areas.
- Flood plains should be mapped, and construction in these areas should be forbidden except under special circumstance.
- Rate and volume of runoff should be regulated, and the level of regulation should be site-specific. In sensitive head-water areas, this regulation may mean zero increase in peak runoff after development.
- Again in some sensitive areas, pollution load from runoff may have to be reduced based on the localized water quality objectives of the receiving streams.
- Finally, multi-objective techniques should be promoted, e.g., multi-purpose ponds. The same pond can serve as an erosion/ sedimentation control during construction, for attenuation of runoff rate for flood control, to increase groundwater infiltration, and for recreation and aesthetic purposes.

In the planning of remedial measures for existing municipalities, the following are recommended:

- As a minimum requirement, combined sewer overflows should be controlled. The appropriate level of control will again be based on the water quality objective of the local receiver.
- Runoff should be reduced through source control.
- In some cases, when a municipality is situated on a sensitive stream with inadequate assimilative capacity, tertiary treatment of sanitary wastes may be prescribed. Under this condition, it may be worthwhile to investigate the feasibility

of controlling the runoff instead of putting in tertiary treatment. This may achieve the same objective, but at less cost.

- Basement flooding should be halted.
- Every existing municipality should carry out an urban drainage planning study to determine the magnitude and effects of its runoff, and to formulate the cost-effective solutions.

Chapter 6

The previous chapters deal with new concepts and improved techniques for managing urban drainage. The purpose of this Chapter is to find out if the present administrative system frame-work is adequately set up to permit and encourage their use, and if not, what can be done to improve the administrative frame-work.

This chapter starts with the examination of the existing common laws and statute laws in Ontario that apply to drainage. Then it proceeds to review how these laws are currently being used to effect drainage control by the various levels of governments, and their overlapping jurisdictional problems at the various stages of the land development or re-development process. Finally the funding programs from the various government agencies for drainage works are also presented.

There are several important conclusions from this Chapter.

(1) There is enough legislation existing in the Province to regulate urban drainage based on pollution and flooding controls. These Acts are such as Ontario Water Resources Act, Environmental Protection Act, Environmental Assessment Act, and Conservation Authorities Act.

(2) Since the urban drainage problems are the result of the change of land use, a more effective way to control the urban drainage problems would be by integrating drainage control with land use planning. This can be done by taking advantage of the provisions of the Planning Act and the Municipal Act and by requiring that the storm water management aspects to be considered at the various stages of the land development approval process.

(3) A table is presented in this Chapter indicating at which stage of the development process, each kind of urban drainage management should be considered; e.g., master drainage planning should ideally be included in the official plan of a municipality, and detailed storm water management measures should be considered at the sub-division planning stage.

(4) It would appear that the existing urban planning and development approval process in Ontario is sufficiently comprehensive to permit the incorporation of storm water management concepts advocated in this Manual. What is required is the recognition and understanding of these by all individuals, municipalities and agencies involved, and a much closer liaison with everyone concerned in order to minimize conflicts and speed up the approval process.

(5) A review of the existing funding programs indicates that drainage works are funded mostly based on conventional concepts such as piped storm sewer systems or dam construction or channel improvement for flood control. Many of the innovative concepts advocated this Manual may not qualify for funding. The Manual Working Committee has recommended that negotiation with major funding agencies, such as CMHC, be proceeded to change the eligibility criteria to include the funding of the construction of these innovative storm water management measures.

Appendix

Finally, in the Appendix, there is a practical example illustrating the step-by-step design of storm drainage for a subdivision. In this example, some of the concepts discussed in the Manual are used, e.g., major-minor concept, source control, such as roof drainage discharged to lawns, roof top storage, subsurface disposal. In addition, in this design, the foundation drain is connected to a third pipe specially for that purpose.

It should be realized that the site chosen for the example is rather ideal, and the case study is over-simplified for demonstration purposes, so that the reader can get some feeling of what is involved in the design. This example should not be regarded as the "recommended Ontario procedure" endorsed by the Manual Working Committee.

SOME OF THE DEFICIENCIES IN THE DRAFT OF THE MANUAL

1. Needless to say, the Manual will require some rearrangement of contents to make it flow better.
2. A condensed version of the Manual is probably necessary in order to focus the key issues.
3. A comparison of the pollution loadings from urban drainage with pollution loadings from agricultural runoff would certainly put the magnitude of these two problems into perspective.
4. Erosion/sedimentation controls perhaps need to be beefed up.
5. Drainage and flood control pertaining to highways and streams are inadequately described; perhaps more input is required from the Ministries of Natural Resources, Transportation and Communications.
6. Thermal pollution effects from runoff are not discussed.
7. Institutional problems, although they have been identified, may require a step-by-step procedure to streamline the incorporation of urban drainage management into the land development approval process.